PB88-131313

Manual of Procedures and Criteria for Inspecting the Installation of Flexible Membrane Liners in Hazardous Waste Facilities

SCS Engineers, Inc., Long Beach, CA

Prepared for

Environmental Protection Agency, Cincinnati, OH

Dec 87

U.S. Department of Commerce
National Technical Information Service
NTIS

PB88-131313

EPA/600/8-87/056
December 1987

MANUAL OF PROCEDURES AND CRITERIA FOR INSPECTING THE INSTALLATION OF FLEXIBLE MEMBRANE LINERS IN HAZARDOUS WASTE FACILITIES

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REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/8-87/056	2.	3. RECIPIENT'S ACCESSION NO. PB88 131313/AS
4. TITLE AND SUBTITLE Manual of Procedures and Criteria for Inspecting the Installation of Flexible Membrane Liners in Hazardous Waste Facilities		5. REPORT DATE December 1987
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas D. Wright, William M. Held, J. Rodney Marsh, Louis R. Hovater		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS SCS Engineers Long Beach, CA 90807		10. PROGRAM ELEMENT NO. BRD1A
		11. CONTRACT/GRANT NO. 68-03-3247
12. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

Project Officer: Charles Moench, Jr. (513) 569-7819

16. ABSTRACT

Under the Hazardous and Solid Waste Amendments (HSWA) of 1984, certain landfills and surface impoundments are required to assure proper containment of wastes by use of liner systems. Proper installation of the flexible membrane liner (FML) must be followed to ensure containment of wastes. This manual is intended to assist an inspector in performing all aspects of a proper FML installation inspection. Four types of FMLs are discussed in this manual: PVC, CSPE, CPE, and HDPE. The manual addresses seven installation operations. These operations include unloading and storage of FML, preparation and maintenance of supporting surface (both earth and other supporting surfaces), placement of FML on the supporting surface, seaming operations, anchoring and sealing (anchoring in earth and to concrete, piping, etc.), testing (both the seams and the integrity of the entire FML installation), and covering the FML (earth, concrete, geotextiles, or drainage nets). The manual describes each operation and sub-operation, and gives recommended inspection procedures, inspection frequencies, and interpretations. The types of documentation necessary for each inspection are discussed. Where appropriate, alternatives to recommended inspection procedures are provided. Inspection checklists are included for each operation to aid the inspector in the field.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 177
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC 17.95/ MF 6.95

NOTICE

The information in this document has been funded by the United States Environmental Protection Agency under Contract No. 68-03-3247 to SCS Engineers. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the U.S. Environmental Protection Agency, permitting and other responsibilities of state and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This document presents the procedures and criteria for inspecting the installation of the four most commonly used flexible membrane liners (FMLs) for land containment of hazardous wastes. The FMLs available for hazardous waste containments and their characteristics are discussed. Installation operations covered include on-site unloading and storage, preparation and maintenance of supporting surfaces, FML placement, seaming, anchors and attachments, testing, and final covering. Finally, inspection checklists are provided to aid the inspector in the field.

The intended audience for this document includes engineering firms, regulatory officials, site operators, and dischargers of wastes to land. Anyone involved in liner installation inspections or in ensuring that design plans and specifications will meet inspection guidelines can benefit from this document.

Thomas R. Hauser, Director
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Research Laboratory

ABSTRACT

Under the Hazardous and Solid Waste Amendments (HSWA) of 1984, certain landfills and surface impoundments are required to assure proper containment of wastes by the use of liner systems. Proper installation of the flexible membrane liner (FML) must be followed to ensure containment of wastes. This manual is intended to assist an inspector in performing all aspects of a proper FML installation inspection.

Four types of FMLs are discussed in this manual: PVC, CSPE, CPE, and HDPE. The manual addresses seven installation operations. These operations include unloading and storage of FML, preparation and maintenance of supporting surface (both earth and other supporting surfaces), placement of FML on the supporting surface, seaming operations, anchoring and sealing (anchoring in earth and to concrete, piping, etc.), testing (both the seams and the integrity of the entire FML installation), and covering the FML (earth, concrete, geotextiles, or drainage nets).

The manual describes each operation and sub-operation, and gives recommended inspection procedures, inspection frequencies, and interpretations. The types of documentation necessary for each inspection are also discussed. Where appropriate, alternatives to recommended inspection procedures are provided. Inspection checklists are included for each operation to aid the inspector in the field.

This manual was submitted in fulfillment of Contract No. 68-03-3247 by SCS Engineers under the sponsorship of the U.S. Environmental Protection Agency. Assisting SCS as a subcontractor was Louis Hovater of Hovater Engineers. All photographs in this manual were provided by Hovater Engineers. This manual covers the period from March 1985 to May 1987, and work was completed as of May 1987.

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CHAPTER 1

INTRODUCTION

DEFINITION OF A FLEXIBLE MEMBRANE LINER

This manual addresses the criteria and procedures for inspecting the installation of flexible membrane liners (FML). For purposes of this manual, an FML is defined as a thin, flexible prefabricated polymeric layer or sheet of plastic or rubber commonly used for the containment of hazardous wastes.

PURPOSE AND NEED FOR MANUAL

This manual is intended to provide criteria and procedures for field inspection of FML installations.

Under the Hazardous and Solid Waste Amendments (HSWA) of 1984, certain landfills and surface impoundments are required to assure proper containment of wastes by the use of liner systems. In all cases, HSWA requires that compacted material be overlain by two FMLs with a leachate collection system installed between the FMLs. Additionally, in the case of a landfill, a second leachate collection system must be installed above the top FML. The liners should consist of one of the following:

- One FML and a compacted low-permeability soil layer (1×10^{-7} cm/sec permeability or less).
- Two FMLs.
- Two FMLs and a compacted low-permeability soil layer.

Proper installation of the FML must be followed to ensure containment of wastes. Other steps include proper design and material selection.

The intent of this manual is to assist an inspector in performing all aspects of a proper FML installation inspection. However, this document does not include inspection procedures for construction of other aspects of a waste containment facility, such as leachate collection systems and low-permeability soil liners.

SCOPE OF MANUAL

The manual is divided into nine chapters. Chapter 1 is an introductory chapter which provides an overview of the manual and briefly describes its use by certain intended audiences.

Chapter 2 discusses the four types of FMLs most commonly used for land containment (PVC, CSPE, CPE, and HDPE), and provides a tabular listing of several other less commonly used FMLs.

Chapters 3 through 9 address the required inspection procedures for each individual step of FML installation at a waste containment site. The various installation procedures covered by each chapter are as follows:

- Chapter 3 - Unloading and storage of FML.
- Chapter 4 - Preparation and maintenance of the FML supporting surface. Both earth and other supporting surfaces (e.g., concrete) are covered.
- Chapter 5 - Placement of FML on the supporting surface.
- Chapter 6 - FML seaming operations, including a brief discussion of the various seaming methods.
- Chapter 7 - FML anchoring and sealing, including anchoring in earth and anchoring of FML to concrete, piping, and other materials.
- Chapter 8 - FML testing, including seam testing techniques and methods for testing the integrity of the entire FML installation (including FML sheets and anchors and seals) for leaks.
- Chapter 9 - FML covers, including earth, concrete, geotextiles, and drainage nets.

Each chapter includes a checklist that lays out the various inspection steps for a specific installation procedure. These checklists are provided in Appendix A. In addition, each chapter is fully contained and can be individually removed from the manual for easy reference during inspection.

INTENDED AUDIENCES

This manual is intended for use by engineering firms, dischargers of wastes to land, operators, and regulatory officials. The manual is intended to provide criteria and procedures for inspecting and testing FML installations in land-based waste containment facilities.

Throughout the inspection process, the inspector will work with representatives of the various participants including the general contractor, the subcontractor(s) and the design engineer. Participants (other than the inspector) include:

- Contractor (includes both the general contractor and any subcontractors). The role of the contractor will be to:
    - Prepare the site for installation of the FML including all necessary vegetation removal, excavation, grading, compaction, and testing.
    - Install the FML.
    - Test the FML installation using nondestructive testing, nondestructive sampling, and destructive testing.
- Design engineer. The design engineer and/or his representative should visit the site as often as possible to ensure that the FML system is being installed according to design, and to answer any questions that may arise in the field regarding the design.
- Membrane manufacturer and/or fabricator. The inspector should request that a representative of these groups visit the site prior to the start of FML installation in order to approve the use of the FML for the intended purpose.

It is the responsibility of the inspector to ensure that installation design plans and specifications are followed. The inspector has the authority to reject the work until the noncomplying item (e.g., improper seaming) is corrected or until field conditions (e.g., ambient temperature is too low/high) warrant restart-up. It is essential that the inspector maintain a cooperative attitude toward FML installers while assuring proper FML installation.

UPDATE OF MANUAL

It is requested that manual users submit ideas and/or suggestions regarding additional/improved installation criteria and procedures to the EPA at the following address for inclusion in subsequent manual updates:

U.S. Environmental Protection Agency
Hazardous Waste Engineering Research Laboratory
Andrew W. Breidenbach Environmental Research Center
Cincinnati, Ohio 45268

PERTINENT REGULATIONS REGARDING USE OF FLEXIBLE MEMBRANE LINERS

Pertinent regulations regarding the use of FMLs include:

- U.S. Environmental Protection Agency Hazardous Waste Management System; Under the Resource Conservation Recovery Act (RCRA). 40 CFR Parts 260, 261, 262, 264, 265, 266, 270, 271, and 280. July 15, 1985.

- U.S. Environmental Protection Agency National Oil and Hazardous Substances Pollution Contingency Plan Under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980. 40 CFR 2-300 FR 31203. July 16, 1982, Effective February 18, 1986.

CHAPTER 2

FLEXIBLE MEMBRANE LINERS AVAILABLE FOR HAZARDOUS WASTE CONTAINMENTS

INTRODUCTION

This chapter provides a brief discussion of the four FMLs most commonly used for waste containment:

- Polyvinyl chloride (PVC).
- High-density polyethylene (HDPE).
- Chlorosulfonated polyethylene (CSPE).
- Chlorinated polyethylene (CPE).

FMLs comprised of other materials are also available and sometimes used for hazardous waste containments. These liner materials, while not discussed in this manual, are listed in Table 2-1.

POLYVINYL CHLORIDE

Polyvinyl chloride (PVC) is produced by any of several polymerization processes from vinyl chloride monomer. PVC is a thermoplastic polymer which is compounded with plasticizers and other modifiers to produce a wide range of physical properties. PVC is a widely used FML for waste containments, due to its comparatively low cost and good physical properties. Though not as resistant to ultraviolet radiation and weather deterioration as other commonly used FMLs, PVC can be expected to provide many years of service if it has a protective cover such as earth.

PVC is initially manufactured in roll stock form and then fabricated into large sheets (up to 30 meters [100 feet] wide by several hundred feet long). PVC membranes are seamed by solvent welding, bodied solvent adhesive, heat, and dielectric methods (see Chapter 6 for a discussion of seaming techniques).

PVC is normally unsupported and used as an FML in thicknesses ranging from 10 to 30 mils. It is also available with fabric reinforcing (supported) in various thicknesses and strengths.

TABLE 2-1. MATERIALS SOMETIMES USED AS FMLs FOR HAZARDOUS WASTE CONTAINMENT*

Polyvinyl Chloride - Oil-Resistant (PVC-OR)
Low-Density Polyethylene (LDPE)
Medium-Density Polyethylene (MDPE)
Linear Low-Density Polyethylene (LLDPE)
High-Density Polyethylene Elastomeric Alloy (HDPE)
Chlorosulfonated Polyethylene - Low Water Absorption (CSPE-LW)
Chlorinated Polyethylene Alloy (CPE-A)
Butyl Rubber (llR)
Polychloroprene (CR)
Epichlorohydrin Plymens (CP)
Polyethylene Ethylene Propylene Alloy (PE-EP-A)
Thermoplastic Nitrile - PVC (TN-PVC)
Ethylene Luterpolymer Alloy (ELA)

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* Some of the above materials are supported with a reinforcing fabric which affects their physical properties, such as increasing their tensile and tear strengths.

HIGH-DENSITY POLYETHYLENE

High-density polyethylene (HDPE) is a thermoplastic crystalline polymer based on ethylene. Its properties are largely dependent on crystallinity and density. HDPE exhibits excellent weather resistance, and is one of the most chemically resistant FMLs available. As a result, its use as a lining for hazardous waste containments is widely accepted. Generally, it is free of additives such as plasticizers and fillers.

HDPE sheets are produced by an extrusion or blown film process in sheet sizes over 9 meters (30 feet) wide by several hundred feet long. The sheets are normally used as an FML in thicknesses ranging from 40 to 120 mils, and are seamed in the field using thermally bonded seams produced by extrusion welding, hot air, and hot wedge (see Chapter 6). HDPE is stiff compared to most other polymeric membranes.

CHLOROSULFONATED POLYETHYLENE

Chlorosulfonated polyethylene (CSPE) is a family of polymers produced by reacting polyethylene in solution with chlorine and sulfur dioxide. CSPE (also known by its trade name Hypalon) is a widely used lining material. It is a synthetic rubber characterized by excellent resistance to weathering and aging. It has good resistance to corrosive chemicals and to growth of mold, fungus, and bacteria, but poor resistance to hydrocarbons.

CSPE is initially manufactured in roll stock form and then fabricated into larger sheets (generally to about 23 meters [75 feet] wide by several hundred feet long). CSPE membranes are seamed by heat sealing, bodied solvent adhesive, solvent welding, and dielectric methods (see Chapter 6). It is normally supported with fabric reinforcing, but is also available in unsupported form. Reinforcing the CSPE increases its tensile and tear strengths and reduces the shrinkage resulting from exposure to the sun. Supported CSPE membranes are normally used as an FML in thicknesses of 36 or 45 mils; unsupported membrane is used in a thickness of 30 mils.

CHLORINATED POLYETHYLENE

Chlorinated polyethylene (CPE) is produced by a chemical reaction between chlorine and a high-density polyethylene. CPE is resistant to ozone attack and weathers well. It also has excellent chemical resistance. Some compounds are serviceable at very low temperatures and are resistant to hydrocarbons.

CPE is initially manufactured in roll stock form and then factory-fabricated into large sheets (up to about 30 meters [100 feet] wide by several hundred feet long). CPE membranes are seamed by bodied solvent adhesive, solvent welding, heat sealing, and dielectric methods (see Chapter 6).

CPE is normally unsupported, but is also available in supported form reinforced with fabric. Reinforcing the CPE increases material tensile and tear strength. Unsupported CPE is normally used as an FML in a thickness of 30 mils; supported CPE, in thicknesses of 36 and 45 mils.

CHAPTER 3

ON-SITE UNLOADING/STORAGE

INTRODUCTION

The handling and storage of FML prior to its installation require careful attention. Improper handling may result in damage to the FML, such as punctures or tears. Depending on the FML material, improper storage may cause damage to the material, such as ultraviolet degradation.

While every job site is unique, certain guidelines should be followed all all sites to provide safe handling and storage. The inspector should be familiar with proper handling and storage practices, and should regularly inspect these practices at a job site.

Relative to the FML, a job site can be divided into three areas: (1) unloading area; (2) storage area; and (3) placement area. Often, the unloading and storage areas are in the same location, whereas the placement area may be located a few hundred feet to over a mile away.

MATERIAL CHECK

When FML material arrives on site, the inspector should ensure that the installation supervisor has carefully checked the material for damage during shipment, and should conduct spot-checks himself. Figures 3-1 and 3-2 provide examples of damage that can occur during shipment.

Packing slips should be checked to ensure that the proper material has been delivered. The material itself should be inspected to verify that it is the right type and thickness. All accessory materials, such as solvents, adhesives, tapes etc., should be examined to make sure that they are the correct type and have not been damaged during shipment.

Inspection Procedures

FML--

- Method: Visually observe that the FML materials delivered to the site are the material type, thickness, and

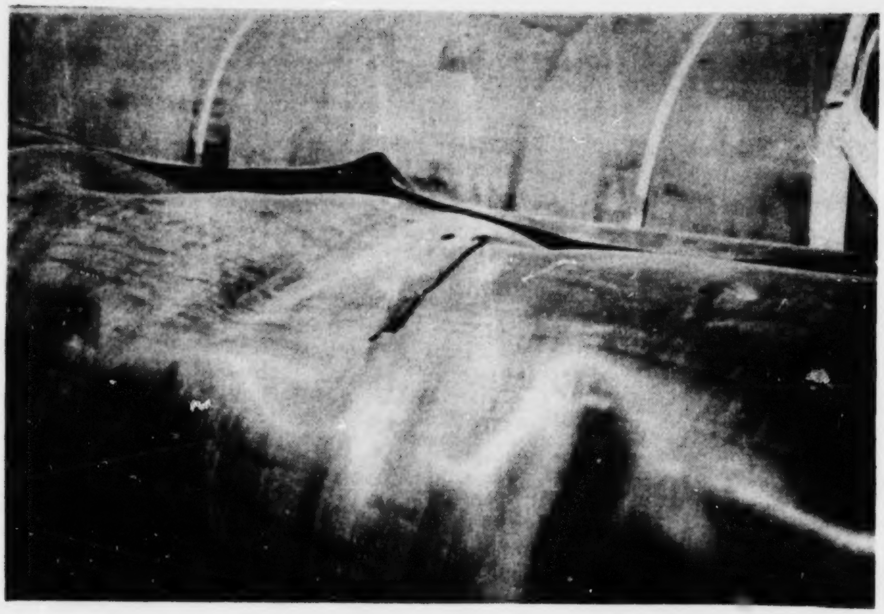

Figure 3-1. FML damaged during shipment

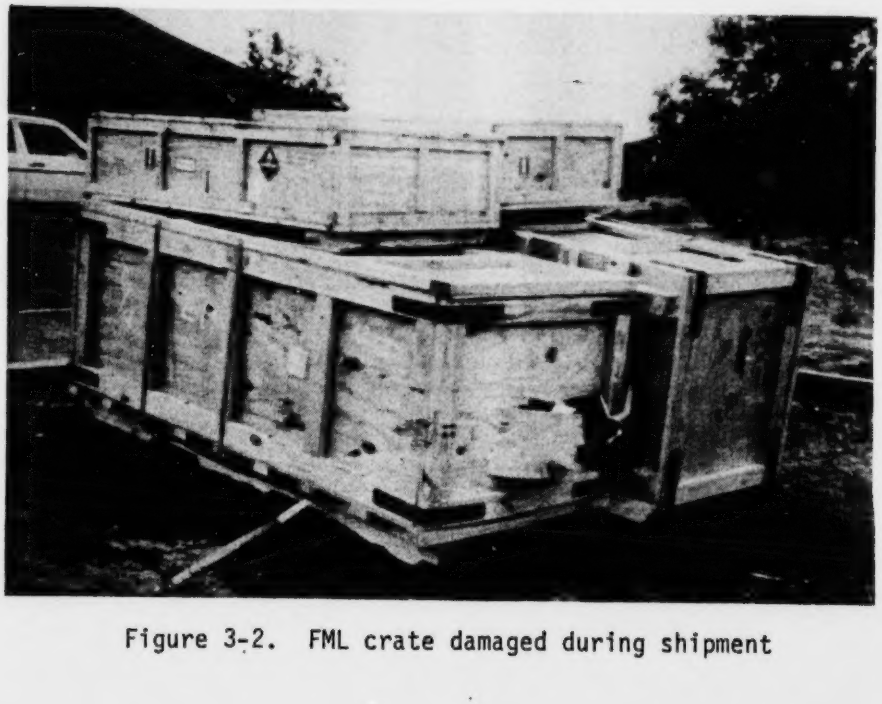

Figure 3-2. FML crate damaged during shipment

quality specified, and that all are unloaded and stored in a manner that does not damage them.

  - Observe FML as it is delivered to the site. Record any packing crates, rolls, or other type packaging that are damaged prior to being unloaded.
  - Observe unloading of FML. Record any packing crates, rolls, or other type packaging that are damaged during unloading operations.
  - Compare the packing slips and any other supplemental shipping information accompanying the FML materials with the specifications to check proper FML type and thickness.

- Frequency: Ongoing observation of FML delivery and unloading.

- Documentation: All observations should be made in a daily diary. All instances of damaged FML and the method of resolution (i.e., either repair or rejection of the FML) must be recorded according to the FML sheet designation.

- Interpretation: All FML used on the project must be as specified. All unspecified FML must be repaired or removed from the site. All scrap FML must be removed from the site upon completion of installation of FML materials; however, pieces of the scrap should be retained and stored by the owner for possible future use.

- Limitations: None.

- Alternatives: None.

Accessories--

- Method: Visually observe that accessories delivered to the site are the material type, thickness, and quality specified, and that all are unloaded and stored in a manner that does not damage them. There are no standard test methods currently in use to inspect solvents, adhesives, cements, caulks, mastics, pads, tapes, etc. Specific observations to be made are included in the Documentation subsection below.

- Location: All containers and packages should be inspected at the unloading area and prior to being placed in storage.

- Documentation: Observations to be documented include the following:

  - Verification that the material complies with project specifications. This includes the certification by the manufacturer or supplier that the material meets or exceeds specifications.

  - Date of manufacture. It is important that the shelf life of the material not be exceeded prior to use.

  - Condition of containers. All containers must be adequately labeled showing brand, type, date of manufacture, and description of proper method of application. All containers must be properly sealed.

- Interpretation: Only materials which meet project specifications and are of acceptable quality shall be installed. Damaged or unacceptable materials shall be replaced.

- Limitations: Visual observations and inspections identify whether the materials are acceptable based on information supplied by the manufacturer. It is not practical to verify all physical properties via laboratory testing.

- Alternatives: None. Visual inspection is a fundamental part of any CQA program. The physical testing of the adhesives used to bond FML to FML is conducted when the required tests for factory and field seams are performed. If a cement (for use in bonding an FML to a concrete surface, for example) needs to be tested, a separate sample could be made by forming a concrete pad and then bonding the FML to its surface.

UNLOADING AND HANDLING EQUIPMENT

The most common equipment used to unload and handle FMLs includes:

- Forklifts.
- Front-end loaders.
- Cranes.
- A-frame winches.

The FML material will generally arrive on site in one of two ways, depending on the material. Polyethylenes usually arrive on site rolled on tubes (see Figure 3-3). These rolls are normally handled by slings (see Figure 3-4), and should not be moved or lifted by using the forks of a forklift or teeth of a front-end loader in contact with the material itself. Other FML materials

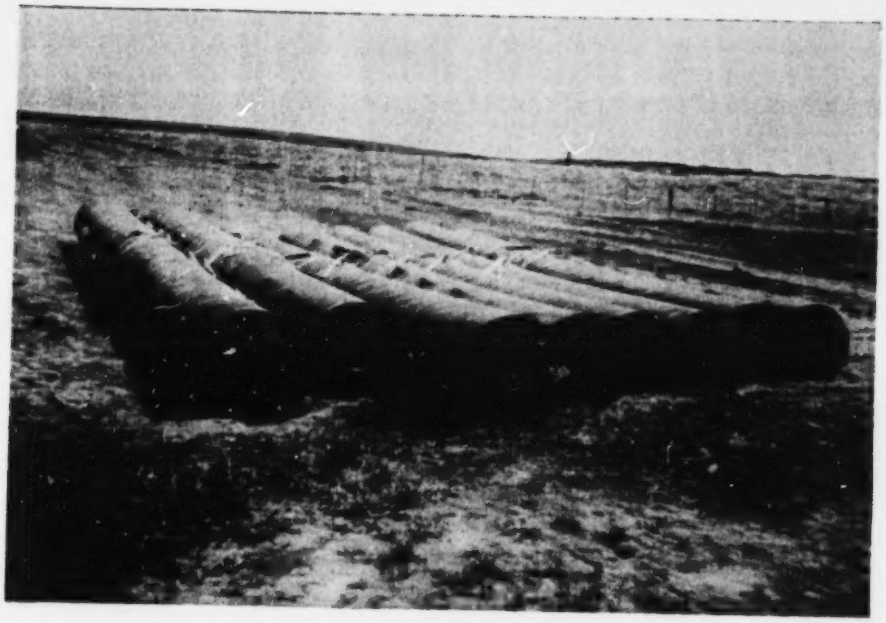

Figure 3-3. Rolls of FML

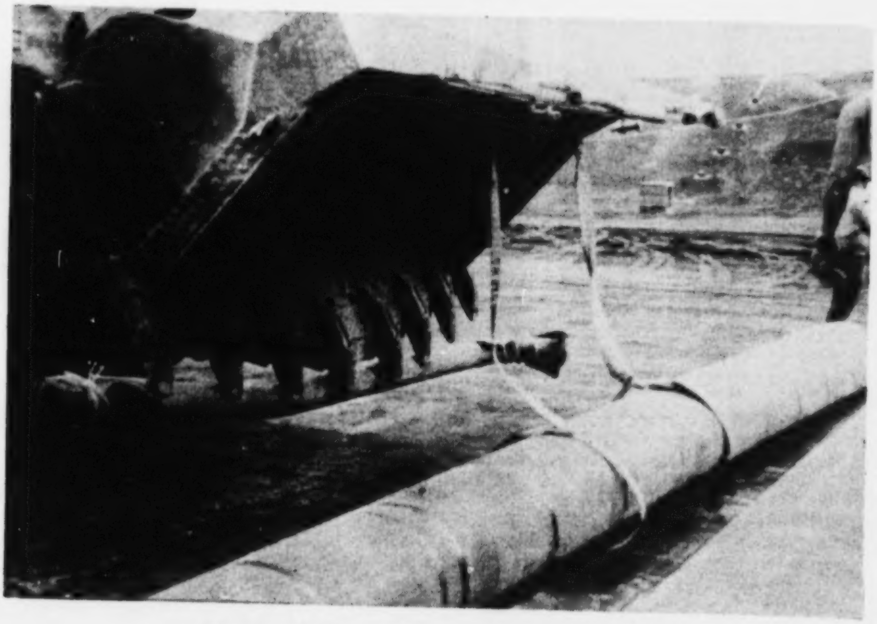

Figure 3-4. FML carrier slings

are normally folded and shipped on pallets (see Figure 3-5) or in crates. Pallets and crates should be handled by a forklift, and care should be taken that the forks do not puncture the packaging (see Figure 3-6).

Inspection Procedures

- Method: Visually observe that the equipment is in working order and capable of being operated in a safe manner. Visually observe that any associated equipment including packaging (such as slings, crates, and pallets) is not damaged and capable of being used in conjunction with other equipment to safely unload and handle the FML materials and accessories. Check all diesel engines to ensure that each has a spark arrester; this will prevent hot carbon particles from escaping through the exhaust system and damaging the FML. Verify that all equipment operators are competent and qualified to operate equipment. Documentary evidence from third-party sources (e.g., equipment operator's license) shall be used for qualification purposes.

- Frequency:

  - Once prior to first use of equipment.

  - Ongoing observation during unloading and handling operations.

- Documentation: The CQA inspector should maintain an accurate log in the daily diary noting the presence, condition, and workability of all equipment. Defective slings, crushed crates, and broken pallets should also be noted. The names of operators (and their designated equipment) directly involved with the installation of the liner should be kept in the daily diary.

- Interpretation: All equipment, including packaging for unloading and handling of FML materials and accessories, must be functioning properly to complete the work in a safe and efficient manner. Slings for hoisting rolls for FMLs must not be frayed or worn. Pallets must be structurally sound to support the folded sheets of FMLs when hoisted; and crates must be fastened securely as a unit to contain the FML during handling. Any faulty equipment, including packaging, must be repaired or replaced prior to use.

- Limitations: It is probable that some equipment will fail to operate properly. To minimize this probability, all equipment should receive the required maintenance to

Figure 3-5. Pallets of covered FML.

Figure 3-6. Transporting FML using forklift

ensure its proper working condition at all times. In the event that a faulty pallet or crate cannot be repaired, it should be completely removed and another method should be used to handle the FML.

- Alternatives: None.

UNLOADING AREA

Accessibility

An important requirement of a proper unloading area is that it be of sufficient size and readily accessible to the delivery vehicles (trucking) and to on-site FML transport and placement equipment. A small, cramped area might necessitate improvising handling procedures that could damage the FML. See Figure 3-7 for an example of a proper unloading area.

Type

Most unloading areas will be open-air with an earth surface. The most important requirement is that the surface be relatively level and smooth, and free of rocks, holes, and debris. This kind of surface may require grading or similar reworking of the area.

If the unloading area is located in a building, proper accessibility and maneuverability, such as that provided by a dock area, are important to facilitate the unloading process.

Location

If the unloading and storage areas are separate, they should be located close to each other and to the placement area in accordance with the requirements for accessibility and surface conditions. Travel distance and degree of slopes along the access route between these areas should be kept to a minimum in order to reduce potential damage to the FML during handling and transport.

Unloading and Handling

FML materials and accessories must be carefully unloaded and handled to avoid damage. Packaging such as crates and pallets must be intact, and slings for hoisting rolls of FML must be adequate. The unloading equipment must be of adequate size and strength to handle the weight. The equipment must not be operated in an unsafe manner (e.g., excessive speed); and the operator should be thoroughly experienced with the particular piece of equipment. Improper unloading and handling methods and techniques may result in damage to the FML and possibly injury to a worker(s).

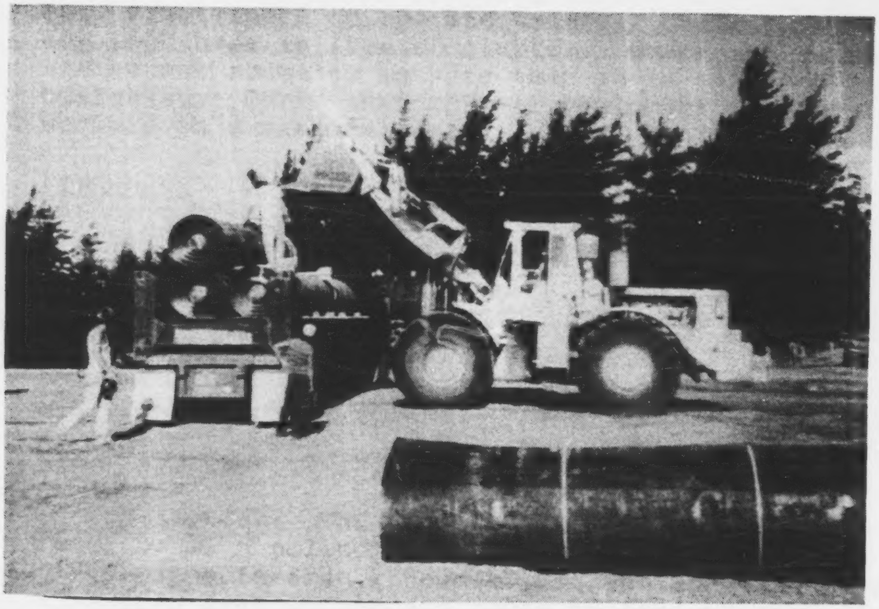

Figure 3-7. Example of a proper unloading area

Inspection Procedures

- Method: Visually observe that the unloading area surface is relatively level, smooth, and free of rocks, holes, debris, and ponded or standing water. Check on accessibility to ensure that trucking and on-site equipment have sufficient space to operate safely. Check to see that any dock area is free of clutter. Check the surface of the access route to be sure that it is safe and free of obstacles. Check that all all equipment is operated by workers in a safe manner.

- Frequency: Ongoing until all FML materials and accessories have been placed and excess materials have been removed from the site or stored in an area designated by the owner.

- Documentation: The CQA inspector should maintain an accurate log in the daily diary noting the status of the unloading area and access route as to surface conditions and accessibility. Infractions pertaining to equipment operation should be noted with the name of the operator, time, and type of infraction.

- Interpretation: The CQA inspector is not expected to function as a policeman monitoring traffic or as a street maintenance foreman. However, it is important that the unloading area and access route be free of obstacles and accessible at all times to minimize potential damage to the FML materials and accessories and to prevent potential injury to workmen. The CQA inspector should serve as a monitor and report on a daily basis to the CQA officer.

- Alternatives: None.

STORAGE AREA

Type

The storage area is often located in the same place as the unloading area, in which case the area must be large enough to accommodate unloading, storage, and transport operations. The storage area surface must be level, smooth, and free of rocks, holes, and debris. If the storage area is located in a building, proper accessibility and maneuverability are necessary to facilitate the transport of FML materials and accessories. A loading dock would be highly beneficial for transport operations. Additionally, open storage areas would be fenced for security.

Location

The storage area should be located close to the placement area to minimize travel by placement equipment. It should also be easily accessible for unloading and placement. A remote storage area may not be cost-effective relative to placement activities due to the travel distance and time required for transport of FML materials.

Climatic Conditions

It is best to store all FML materials and accessories in a location out of direct contact with weather conditions. It is important that PVC and CSPE be protected from the sun prior to installation and stored in a covered, ventilated area (see Figure 3-5). Heat from the sun causes CSPE to cure; when this occurs, field seams become more difficult to make. The sun also causes ultraviolet degradation of PVC. HDPE and CPE are not affected by the sun as much as other FMLs, but ambient temperatures greatly impact any FML when it is unfolded or unrolled. Also, blocking or sticking of an FML may occur, causing delamination or tearing of the FML. Further, folded FMLs exposed to rain or snow can capture water in the folds, making the FML package more difficult to handle and more susceptible to damage during transport to the placement area. Wind may cause an unprotected FML to unfold, resulting in damage such as tearing and/or shredding. Finally, it is best to store all accessories, such as adhesives, cements, solvents, mastics, caulks, tapes, and welding resins, inside a sheltered area.

Other Factors

Where it is practical, material in the storage area should be arranged so that older material is used before newer material. Also, many projects have specific sheet numbers based on a sheet layout plan. Storage should therefore be planned so that the sheet numbers needed (according to the sheet layout plan) are readily accessible.

Inspection Procedures

- Method: Visually observe that the storage area surface is relatively level, smooth, and free of rocks, holes, and debris. Check accessibility to ensure that unloading and placement have adequate space to operate safely. Confirm that dock area, if applicable, is free of clutter. Check the surface of the access route from the storage area to the placement area to be sure that it is safe and free of obstacles. Check the storage area to be sure it is secured. Verify that FML material is stored such that older material is used before newer material, and that numbered sheets are stored for ready access as needed for placement. Observe that the FML materials, particularly PVC and CSPE, are stored in original unopened rolls and crates, off the ground, in a dry area, and protected from the sun by a lightweight, opaque cover in a manner that allows a free-flowing air space between the crates and cover. Observe that all accessories are protected from climatic conditions and stored preferably inside a sheltered area.

- Frequency: Ongoing until all FML materials and accessories have been placed and excess materials have been removed from the site or stored in an area designated by the owner.

- Documentation: The CQA inspector should maintain an accurate log in the daily diary noting the status of the storage area and access route to the placement area as to surface conditions and accessibility. Infractions pertaining to equipment operation should be noted with the name of the operator, time, and type of infraction. Transport of materials into and out of the storage area should also be noted in the daily diary.

- Interpretation: The CQA inspector is not expected to function as a policemen monitoring traffic or as a street maintenance foreman or warehouseman. However, it is important that all activities within the storage area be observed and recorded, and a report made on a daily basis to the CQA officer.

- Alternatives: None.

CHAPTER 4

PREPARATION AND MAINTENANCE OF SUPPORTING SURFACE

INTRODUCTION

For purposes of this manual, the supporting surface is defined as the surface on which the FML will be placed. For a single FML system, the supporting surface will probably consist of compacted earth, concrete, asphalt, or other material. If a second FML is specified (a double FML system), the supporting surface for the top FML will generally consist of a drainage net, a granular soil layer, and/or a geotextile fabric.

Whether a single or double FML system is specified, it is assumed that the supporting surface has been brought to final grade, and that the earth subgrade (if applicable) has been compacted and is structurally sound.

EARTH SUPPORTING SURFACES

Type of Soil

Earth supporting surfaces can consist of a variety of soil types. Each soil type has specific characteristics that need to be considered with regard to FML installations. For example, clayey soils form surface cracks when dried, and sandy soils form depressions under foot and vehicular traffic. Table 4-1 shows some characteristics pertinent to FML installations.

Vegetation Removal

While it is not a common occurrence, FMLs have reportedly been penetrated by underlying vegetative growth. It is recommended that all vegetation be removed prior to placement of the FML. In addition, herbicides are often recommended to completely kill any remaining vegetation and/or seeds that could grow after the FML is placed.

If the inspector feels that the site has an undesirable amount of vegetation or is prone to future growth beneath the FML, and vegetation removal and/or use of a herbicide is not specified, he should contact the CQA officer or design engineer.

TABLE 4-1. SOIL CHARACTERISTICS PERTINENT TO FML INSTALLATIONS, USCS

USCS Symbol	Name	Drainage Characteristics*	Erosion Characteristics		Compaction Characteristics	Comments
			Water	Wind		
GW	Well graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Excellent	Good, tractor, rubber-tired, steel-wheeled roller, moisture addition	Forms depressions under foot and vehicle loading
GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Excellent	Good, tractor, rubber-tired, steel-wheeled roller, moisture addition	Forms depressions under foot and vehicle loading
GM	Silty gravels, gravel-sand-silt mixtures	Fair to poor	Good	Very good	Good, with close control, rubber-tired, steel-wheeled roller, moisture addition	Stable when dry
GC	Clayed gravels, gravel-sand-clay mixtures	Poor to practically impervious	Very good	Good	Fair, rubber-tired, steel-wheeled roller, moisture addition	Stable when dry
SW	Well graded or gravelly sands, little or no fines	Excellent	Very good	Very good	Good, tractor, steel-wheeled roller, moisture addition	Forms depressions under foot and vehicle loading
SP	Poorly graded sands or gravelly sands, little or no fines	Excellent	Very good	Very good	Good, tractor, steel-wheeled roller, moisture addition	Forms depressions under foot and vehicle loading
SM	Silty sands, sand-silt mixtures	Fair to poor	Fair	Good	Good, with close control, rubber-tired, vibratory roller	Stable when dry
SC	Clayed sands, sand-clay mixtures	Poor to practically impervious	Fair	Fair	Fair, vibratory roller, rubber-tired	Stable when dry, forms surface crack if wet, then dry
ML	Inorganic silts and very fine sands, rock flour, silty or clayed fine sands or clayey silts with slight plasticity	Fair to poor	Very poor	Fair	Good to poor, close control essential, rubber-tired roller, vibratory roller	Stable when dry
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, loam clays	Practically impervious	Very poor	Fair to poor	Fair to good, vibratory roller, rubber-tired	Stable when dry, forms surface crack if wet, then dry
OL	Organic silts and organic silt-clays of low plasticity	Poor	Poor	Fair	Fair to poor, vibratory roller	Stable when dry
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, clastic silts	Fair to poor	Poor	Fair to poor	Poor to very poor, sheepsfoot roller	Stable when dry
CH	Inorganic clays of high plasticity, fat clays	Practically impervious	Fair to poor	Poor	Fair to poor, vibratory roller	Stable when dry, forms surface cracks if wet, then dry
OH	Organic clays of medium to high plasticity, organic silts	Practically impervious	Fair to poor	Fair to poor	Poor to very poor, vibratory roller	Stable when dry, forms surface cracks if wet, then dry
PI	Peat and other highly organic soils				Not recommended for FML installations	

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* Values are for guidance only; design should be based on test results.

† The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.

Areas that would be most prone to future vegetative growth after FML placement would be those with:

- A warm, moist climate.
- A supporting surface that has been exposed for an extended period of time (e.g., several months) and may have been covered by a variety of windblown seeds.

Inspection Procedures--

The following procedures should be performed for inspection of vegetation removal prior to placement of the FML on the supporting surface:

- Method: Visually observe supporting surface to ensure the following:
    - All vegetation and large roots are removed.
    - If a herbicide is specified, all areas of the supporting surface are thoroughly covered, and the herbicide is applied in accordance with the manufacturer's specifications. Figure 4-1 shows the application of a herbicide at an FML site.
    - Time is allowed for the herbicide to be absorbed in the soil or to lose its volatile components so that it will not react with the liner.
    - Rain does not wash the herbicide from the area before it can be effective.
    - If the herbicide was applied at the site without observation by the inspector, a contractor's certification verifying that the herbicide was applied per manufacturer's specifications should be obtained.
- Location: The entire supporting surface should be observed.
- Documentation: The inspector should keep accurate records in the daily diary, noting the type of vegetation removed, size (e.g., were large roots removed?), type of herbicide used, and personnel applying herbicide.
- Interpretation: All vegetation must be removed.
- Limitations: In order to assure the effectiveness of the herbicide, it must be applied according to specifications.
- Alternatives: No herbicide application.

Figure 4-1. Application of herbicide

Burrowing Animals, Ants, and Other Pests

The inspector should observe the supporting surface area to detect the presence of burrowing animals (e.g., gophers and ground squirrels), ants, or other pests (see Figure 4-2). If their presence is noted, the inspector should advise the CQA officer or design engineer of the problem. Once the appropriate course of action has been taken, the inspector's tasks are as outlined below.

Inspection Procedures--

- Method: Visually observe the entrapment, poisoning, or other elimination of burrowing animals, ants, or other pests. Observe the collapsing and/or filling of animal burrow tunnels and/or ant chamber passages, as necessary.
- Location: Wherever FML is to be placed and an extended area around the placement area as determined by the CQA officer or design engineer.
- Documentation: Obtain certification from the contractor stating that all of the above work has been performed. Enter certification information and visual observations in the daily diary.
- Interpretation: All burrows and chamber passages should be collapsed and/or filled.
- Limitations: It may be difficult to assure that all burrows and chamber passages are collapsed/filled.
- Alternatives: None.

Preparation of Finished Earth Supporting Surface

A variety of factors affect the degree of effort required to prepare the finished earth supporting surface. These include:

- Type of soil. All soils differ with regard to the amount of effort required to prepare them as an acceptable supporting surface. Gravelly and sandy soils may lack a sufficient amount of fines, and clayey soils may be too hard and fractured. Both soil types often require the addition of other materials to provide an acceptable surface. Generally, however, most on-site soils can be prepared as an acceptable surface.
- Type and thickness of FML. A thinner FML (e.g., 30 mil) will require a smoother surface than a thicker FML (e.g.,

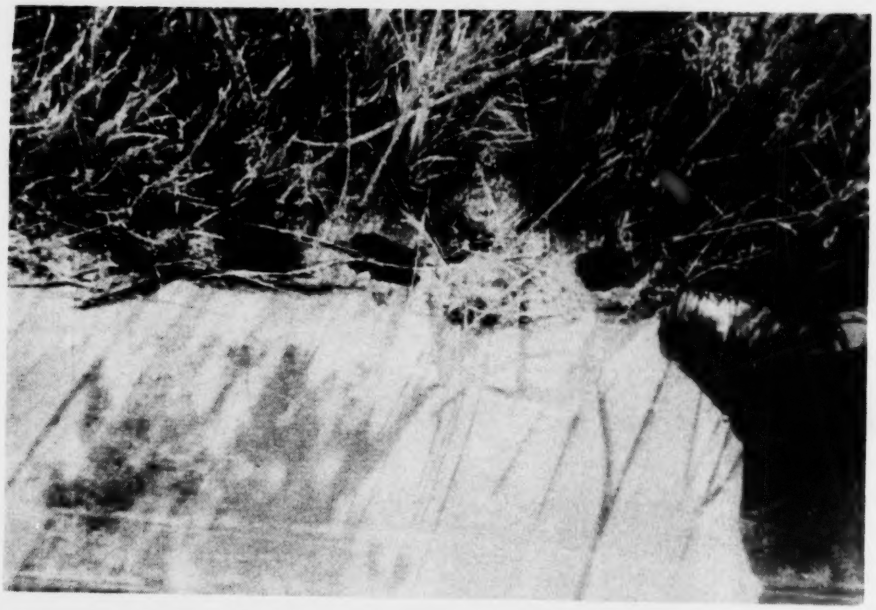

Figure 4-2. Animal burrow holes at edge of supporting surface

100 mil). Depending on the type of FML, fabric-reinforced materials generally offer greater resistance to punctures caused by imperfections in the supporting surface, and can tolerate a less smooth surface than an unreinforced material of the same thickness. Regardless, every effort should be made to prepare a proper subgrade.

- Hydraulic head or load to be placed on the FML.

In some cases, the exposed surface of a rock outcrop may be present. If the outcrop is not too severe, it may be covered with a layer of additional soil, one or more sections of FML, or geotextile to mitigate its effect on the primary FML. Figure 4-3 shows a rock outcrop that was successfully prepared for FML placement. Removal of all grade stakes and elimination of soil test holes is very important.

Inspection Procedures--

The first step in the preparation of the finished earth supporting surface is to manually remove all clods, pebbles, etc., from the surface, and to fill in the voids (see Figure 4-4). The inspector's tasks in this operation are as follows:

- Method: Visually inspect the supporting surface to ensure the following:
    - There are no rocks or other objects larger than USCS sand (SP) on the surface.
    - There are no petroleum products or other spills.
    - All soil test holes are properly backfilled and compacted.
    - It is free of any wet areas and has a uniform moisture content.
    - It is free of all grade stakes, roots, and other foreign matter.
    - It is free of ravelling, ruts, depressions, and abrupt changes in grade.
- Location: Entire supporting surface.
- Documentation: The inspector should maintain an accurate record of areas where rock outcrops were removed to obtain a proper surface, as well as areas that had to be worked to remove excess water or contaminant spillage from the surface soils. The inspector should record the location of all soil test holes and should note that all grade stakes were removed. The inspector should record this information in the daily diary.

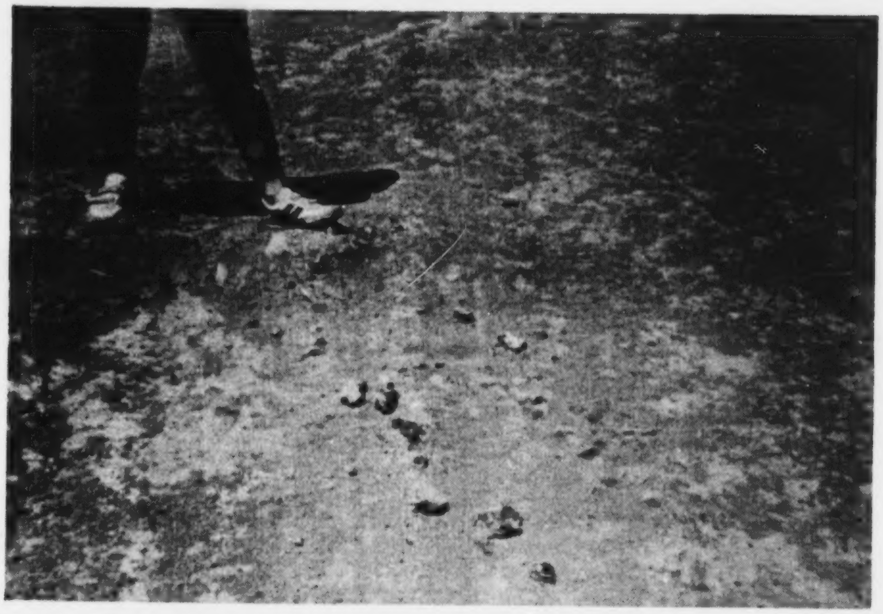

Figure 4-3. Rock cutcrop in supporting surface

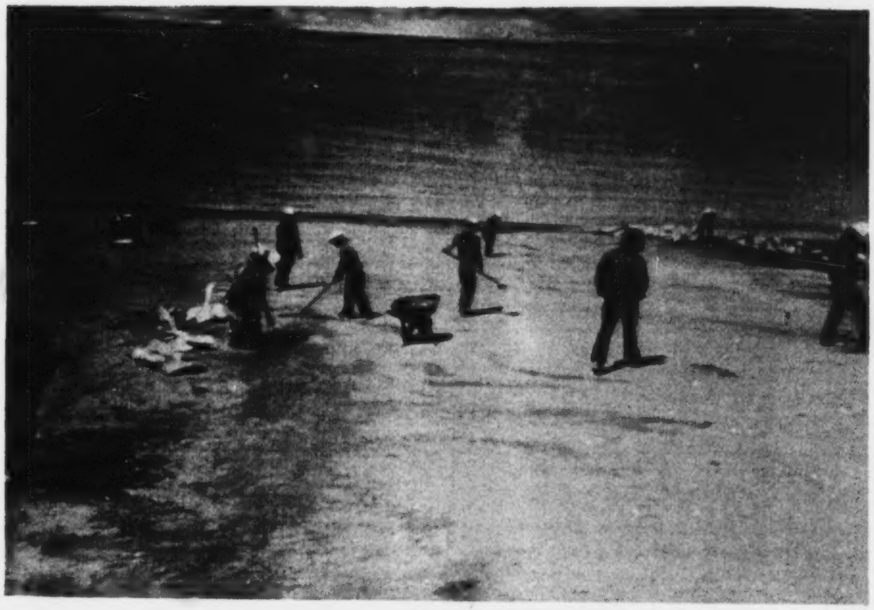

Figure 4-4. Hand removal of rocks, etc. from supporting surface

Once the hand-finishing has been completed, the surface should be rolled and compacted. The type of equipment used will depend on the soil type. Usually, a smooth steel-wheeled roller is used for soils such as loose sand or silty sand; a vibrating roller is used for other soils. Two coverages by the roller are generally required. Areas not accessible to the roller are compacted by approved mechanical or hand tampers. Figures 4-5 and 4-6 show an operator-ridden vibratory roller and a smooth hand-held vibratory roller, respectively.

The inspector's responsibilities with regard to surface compaction are as follows:

- Method: Visually inspect the supporting surface as it is prepared to ensure that it is smooth and free of debris and foreign matter.

- Location: Entire supporting surface.

- Documentation: Record results of observations in the daily diary.

- Interpretation: The surface should be smooth and ready for liner placement (see Figure 4-7).

- Limitations: None.

- Alternatives: None.

Maintenance of Earth Supporting Surface

It is important to maintain the integrity of the supporting surface after it has been accepted for FML placement. The following events must be mitigated or corrected if they occur:

- Wind erosion of the soil fines.
- Storm water erosion.
- Saturation of and/or ponding by storm water.
- Depressions due to foot and vehicular traffic.
- Dragging of FML edges during placement.

Wind Erosion--

Wind erosion can be minimized by:

- Keeping the surface moist, especially during windy periods (see Figure 4-8).

- Preparing only an area of supporting surface that can be covered by FML the following day, i.e., schedule supporting surface preparation only one day ahead of FML placement (see Figure 4-9).

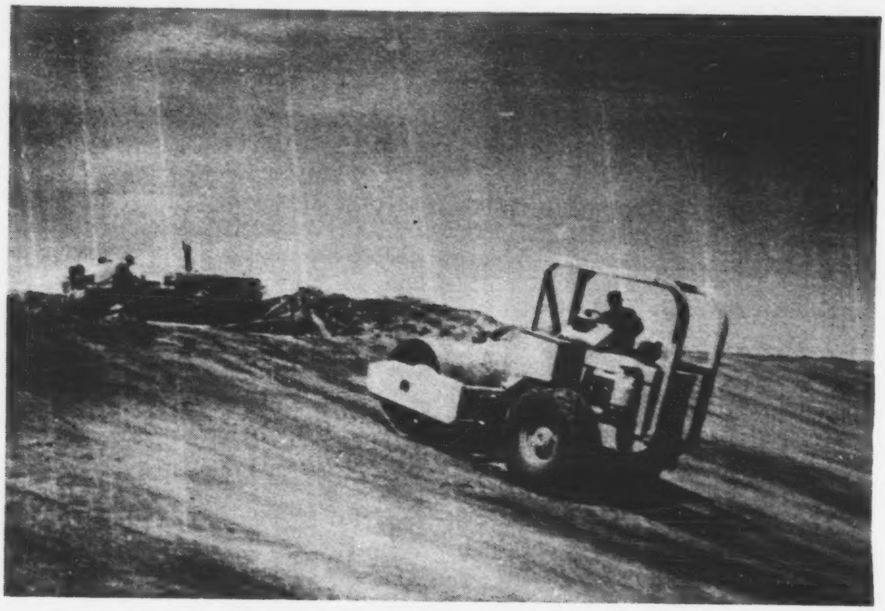

Figure 4-5. Vibratory roller on supporting surface.

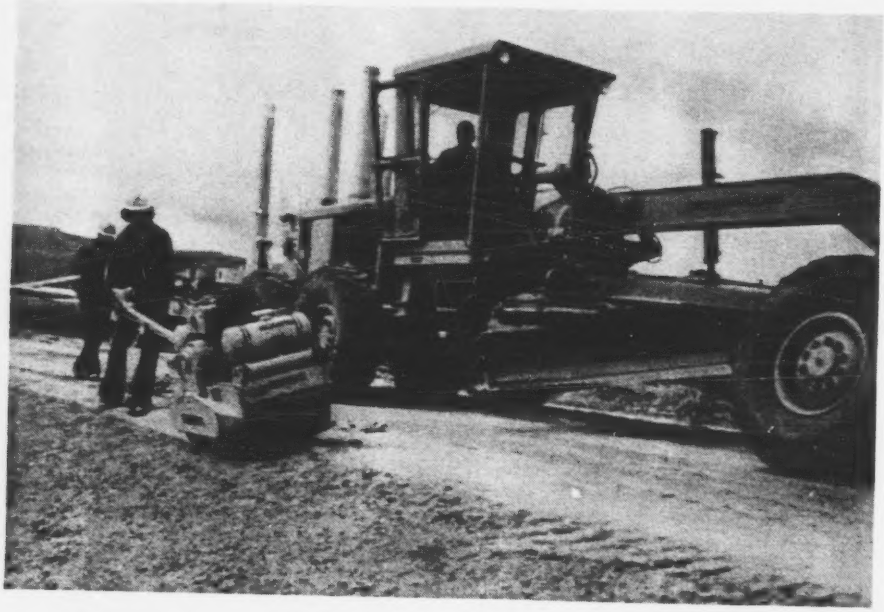

Figure 4-6. Smooth hand-held steel-wheeled roller on supporting surface.

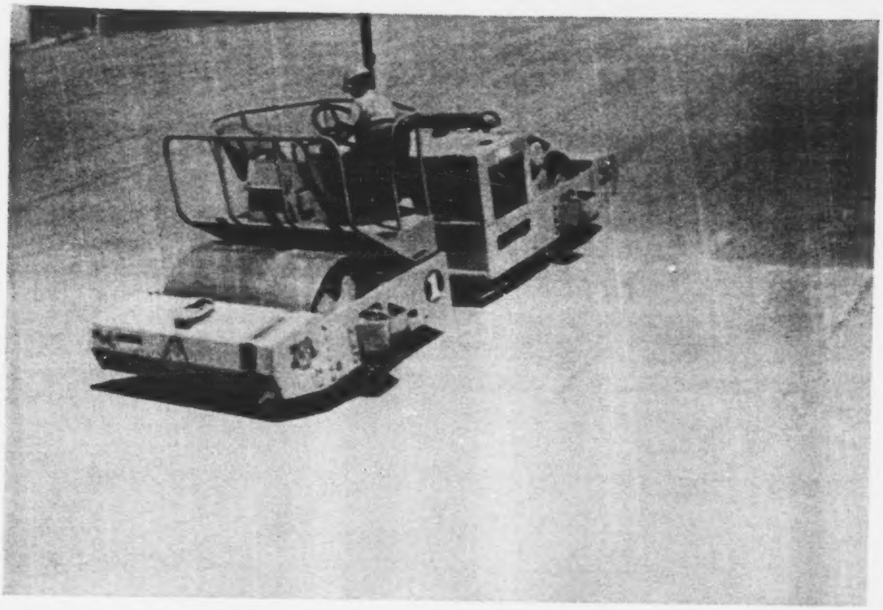

Figure 4-7. A properly prepared final supporting surface

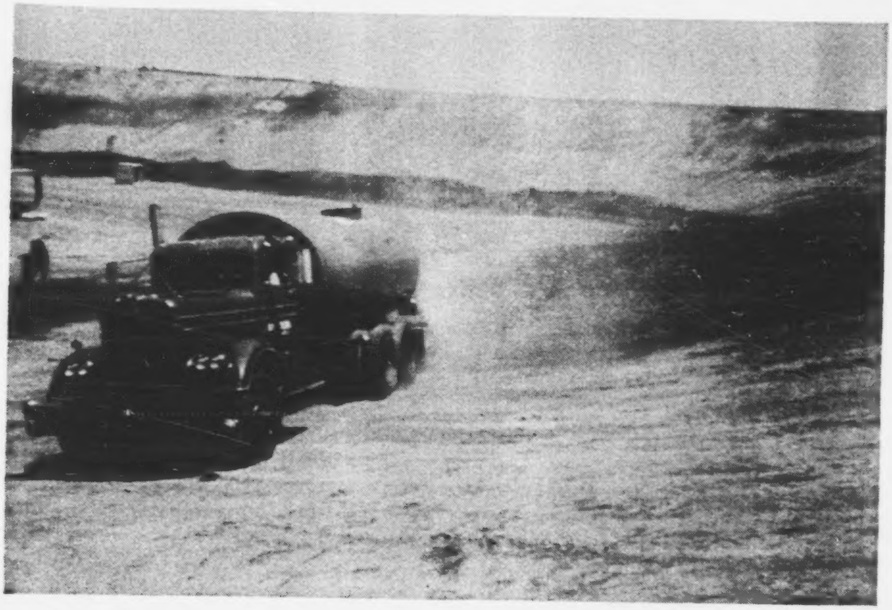

Figure 4-8. Moistening of supporting surface

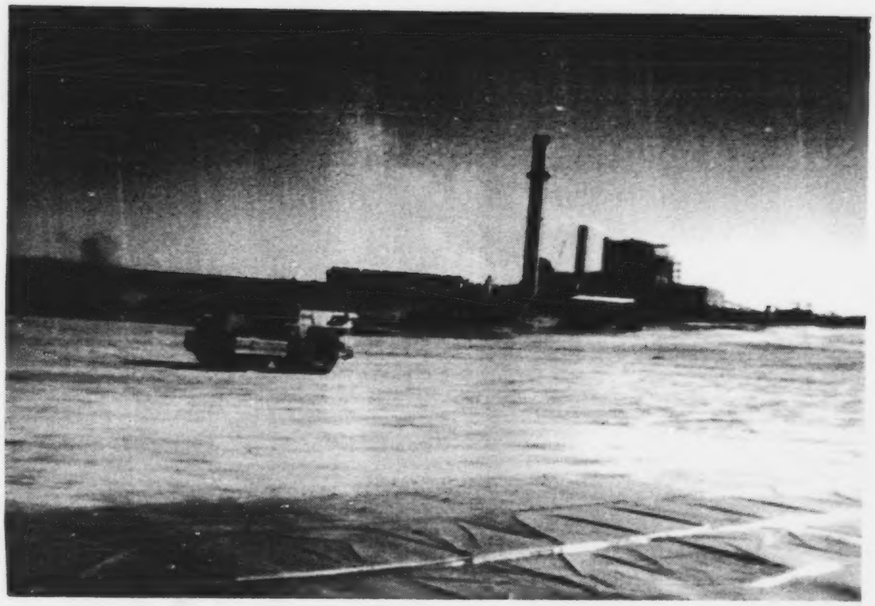

Figure 4-9. Partially placed FML

Storm Water Erosion--

Storm water erosion can be minimized by:

- Placing the FML on the side slopes first. The FML should be at least temporarily anchored at the top of the slope (refer to Chapter 8) to keep storm water from running under the FML and eroding the side slope under the FML. If this occurs, the FML must be rolled away and the side slope supporting surface repaired. Figure 4-10 illustrates an eroded side slope.

- Preparing only an area of supporting surface that can be covered by FML the following day, taking into consideration inclement weather forecasts.

Saturation and/or Ponding by Storm Water--

Saturation or ponding by storm water will not adversely affect sandy soils. However, it is not possible to mitigate this problem with other soils; still, the effect can be minimized if all potential run-on is diverted around the FML placement area. If an area of the supporting surface becomes saturated or has ponded water after a storm, the surface must be allowed to dry. If water has found its way under the in-place FML, the FML must be rolled back to allow the area to dry (see Figure 4-11). Wet areas under in-place FML can be located by walking on the FML and sensing for soft spots and by looking for gullies that run under the FML and low spots.

Depressions Due to Foot and Vehicular Traffic--

Damage to the supporting surface can be minimized by:

- Keeping vehicular traffic off the finished supporting surface.

- Provision of support ladders on the steep side slopes so that workers are not required to dig their feet into the slope for support while placing the FML. Ladders should be constructed so that they do not create their own depressions in the slope. Figure 4-12 shows an unprepared supporting surface slope face with foot/traffic-created depressions.

The following summarizes the inspector's responsibility with regard to supporting surface maintenance:

- Method: Visually inspect the supporting surface for evidence of damage. Walk on in-place FML after a storm to detect soft, wet spots.

- Location: Entire supporting surface.

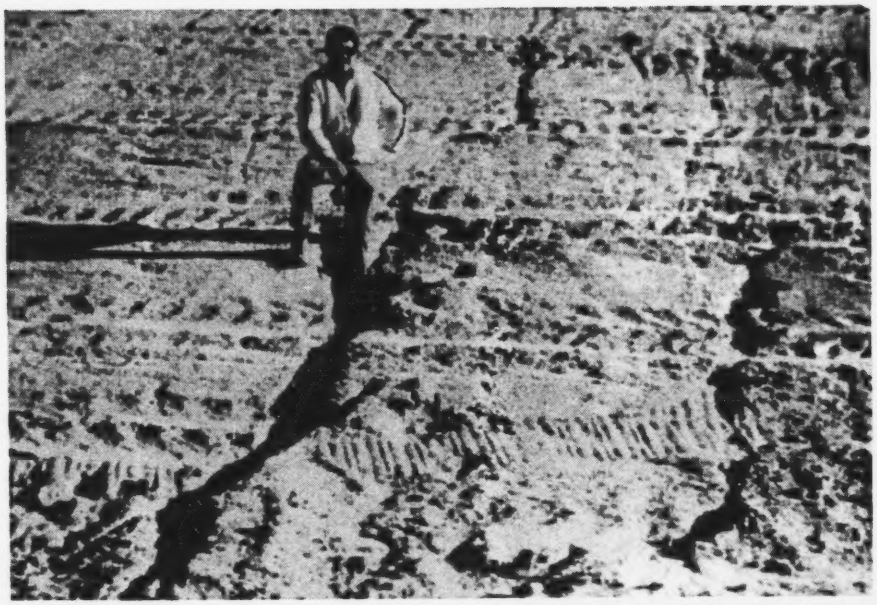

Figure 4-10. Eroded side slope

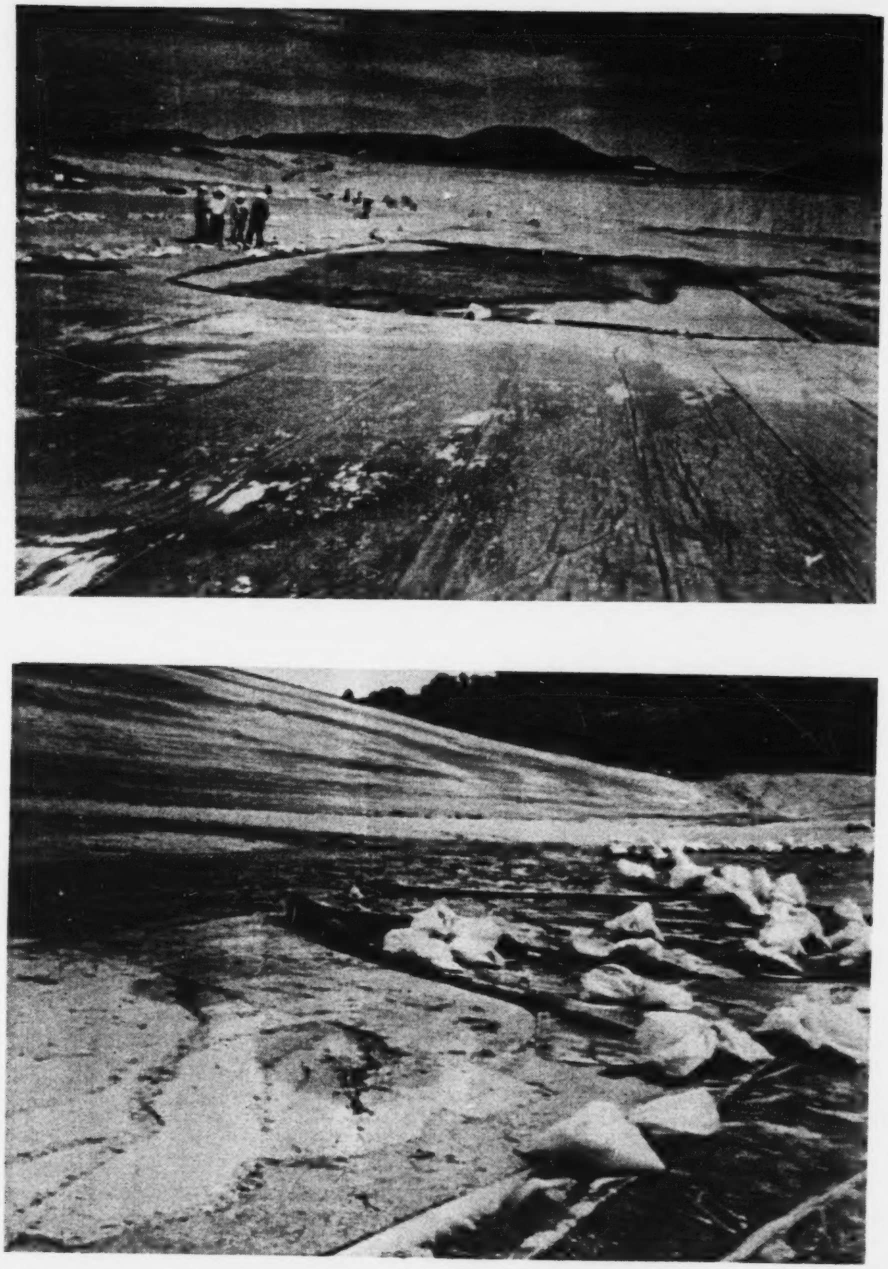

Figure 4-11. Wet supporting surface exposed for drying

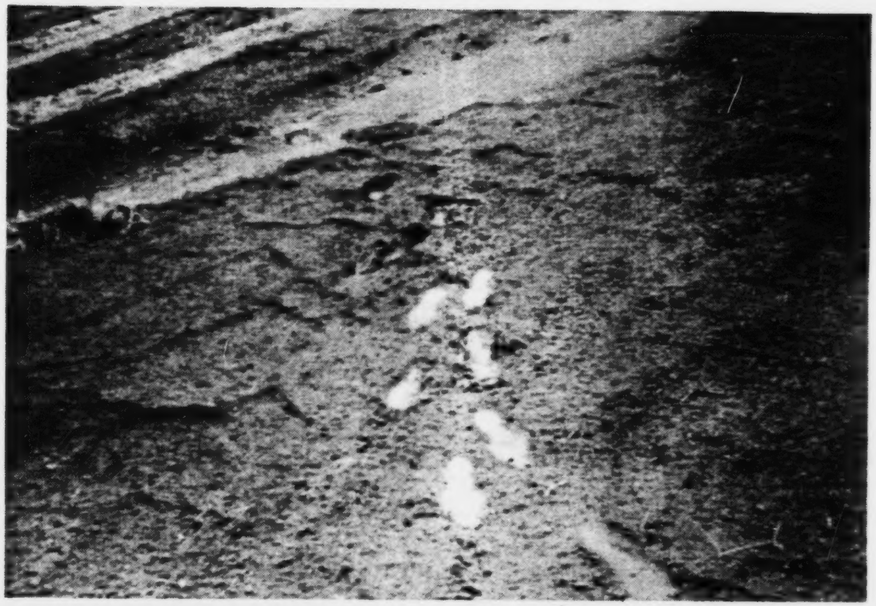

Figure 4-12. Unprepared supporting surface slope face with foot depressions.

- Documentation: Record results of observations in the daily diary.

- Interpretation: All damage must be repaired so that the supporting surface is again ready for FML placement.

- Limitations: None.

- Alternatives: None.

OTHER SUPPORTING SURFACES

Concrete

In many cases, an FML may be placed on a concrete surface. The concrete might be new (poured recently with the intent of being the FML supporting surface) or old (an older structure that is being retrofitted with an FML). Many of the items to be inspected are similar for both old and new concrete. These are discussed below.

Inspection Procedures for Old or New Concrete--

- The surface must be checked for voids and projections such as aggregate, forms, re-bar, or excess mortar (see Figure 4-13 for an example of an unacceptable concrete supporting surface).

- The finish should be a steel trowel finish (see Figure 4-14).

- All expansion joints should be cut flush.

- There must be rounded edges at all corners coming into contact with the FML.

- The surface must be checked for voids both visible and hidden in concrete.

- There should be no abrupt changes in the surface (abutting surfaces).

- Where there is a transition joint between different materials, as in the case of earth to concrete, check it should be confirmed that the earth was compacted properly adjacent to the concrete to prevent subsequent differential settlement.

Special inspection requirements for old concrete--Old concrete must be observed very carefully, because it is more likely to have cracks, surface chipping, and a rougher surface. Old concrete is also more likely to chip and crack when drilling is

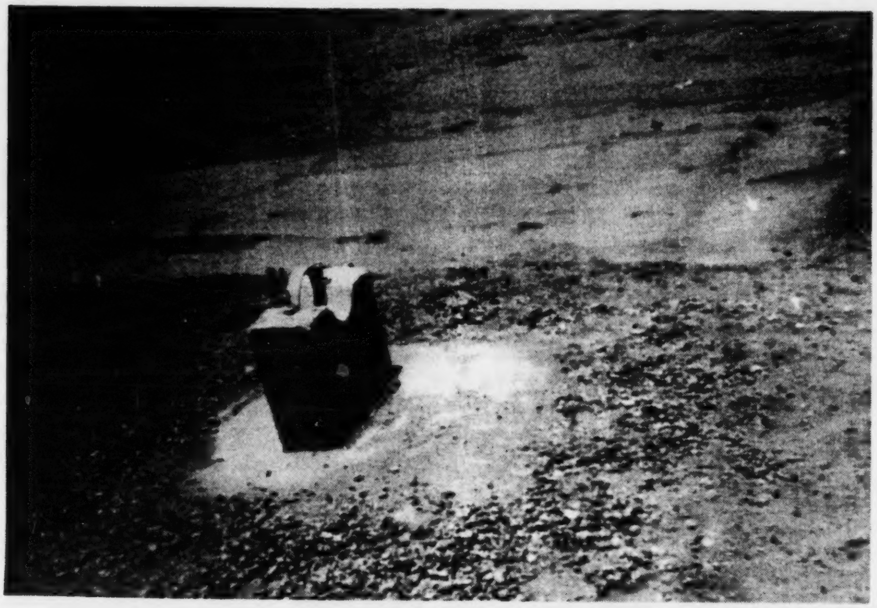

Figure 4-13. Unacceptable concrete supporting surface

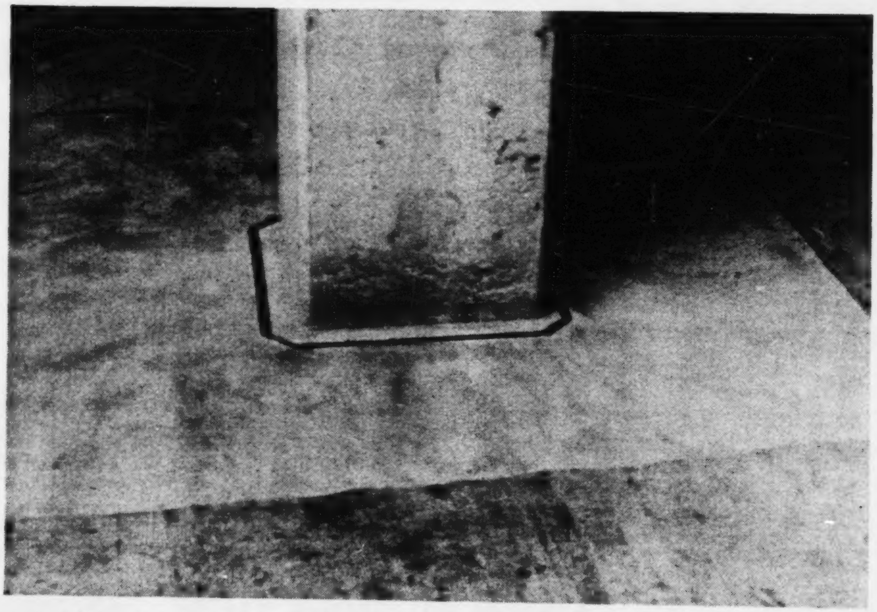

Figure 4-14. Concrete supporting surface with an acceptable trowel finish

required to set the FML anchor bolts. The effects of surface irregularities may be minimized by the use of various coating materials or by covering with a geotextile.

The inspector should also check to see that any vegetation and/or other debris has been removed from cracks in the concrete. Generally, if vegetation is present, it should be treated with a herbicide, since it is difficult to determine that all roots have been removed.

Special inspection requirements for new concrete--New concrete must have been allowed to age at least 28 days in order to obtain the strength needed to set FML anchor bolts. In addition, any wax-type curing compound used must be removed prior to FML placement, since sealing compounds (adhesives, cements, and caulks) will not adhere to this type of surface. If surface voids exist, they must be eliminated by sacking with cement grout.

Asphaltic Supporting Surfaces

Asphaltic supporting surfaces are also used for FML placement. The items to check when inspecting an asphaltic surface include:

- Surface voids. Surface voids can be filled with a variety of suitable materials or covered with a geotextile. Figure 4-15 shows a surface coating being applied to an unacceptable asphaltic supporting surface to fill the surface voids.

- All debris removed from the surface. This can be accomplished by sweeping.

- Presence of ravelling. Areas not properly rolled when hot will often result in aggregate that is loose on the surface.

For all rigid surfaces, the inspection routine should be as follows:

- Method: Visually inspect the supporting surface for abrupt grade changes, projections, voids, and rocks or pebbles.

- Frequency: As necessary after the supporting surface is in place.

- Location: Entire supporting surface.

- Documentation: Record results of observations in the daily diary.

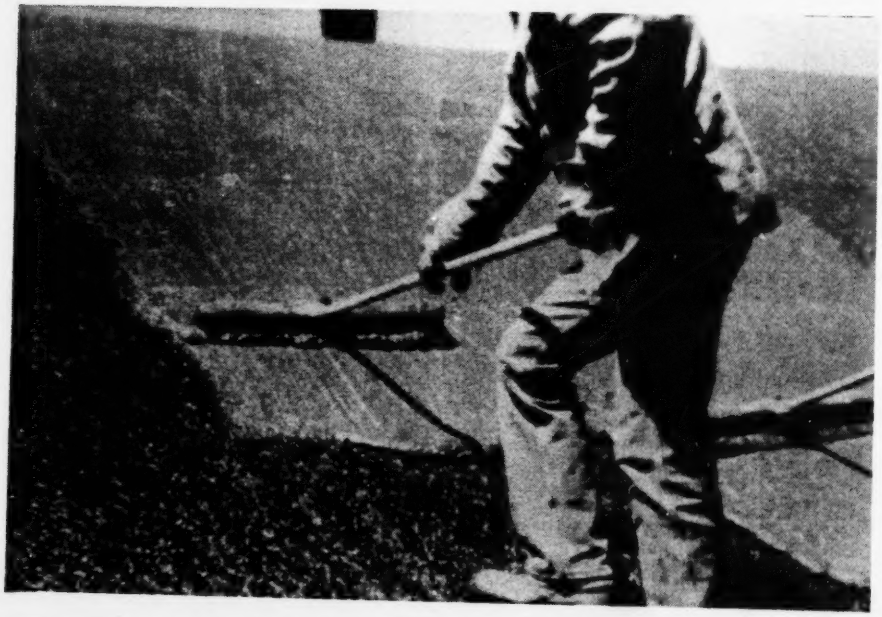

Figure 4-15. Surface coating being applied on an unacceptable asphaltic supporting surface.

- _Interpretation_: Any abrupt grade changes, projections, and rough surfaces must be smoothed/eliminated.

- _Limitations_: None.

- _Alternatives_: Supporting surface could consist of soil, or geotextiles.

CHAPTER 5

PLACEMENT OF FML ON SUPPORTING SURFACE

INTRODUCTION

Placement of FML on a supporting surface involves the following procedures:

- Transporting the FML to the working area.
- Removing the FML from its packaging.
- Spreading the FML sheets in their appropriate locations, checking that each sheet is undamaged (i.e., has no holes, etc.) and ready for seaming.

Prior to commencing placement of the FML, the inspector should first ensure that:

- Placement equipment is on-site and in working order.
- A sufficient number of qualified placement personnel are on site.
- Weather conditions are suitable.

PLACEMENT EQUIPMENT

Various types of large construction and hand-held equipment are required for placing FML. Table 5-1 lists the equipment required for placement of FML. Figures showing examples of equipment used for FML placement are provided throughout the chapter.

Inspection Procedures

- Method: Observe all placement equipment to ensure that appropriate types and quantities are on site. Observe the check-out of each piece of equipment to ensure that they are in proper working order.

TABLE 5-1. EQUIPMENT FOR FML PLACEMENT

Item	Use
Forklift, front-end loader, and/or flatbed truck	To handle FML sheets for placement
Ladders, wood, flat type	To work on slopes
Wood or plastic dowels with rounded ends, and/or mechanical grips	To assist workers in pulling on edges of FML panels while placing
Chalk line	To assist placing of FML panels
Tape measure (100 feet long)	To measure FML sections
Scissors (bright-colored with rounded points), knife	To cut FML materials
Grade stakes or traffic cones	To measure soil cover depths
Sandbags	To secure unseamed FML panels to prevent damage by wind
Red and yellow keel	To mark FML
Arch punch	To cut holes in FML to fit over anchor bolts
Utility knife, metal sheers	To cut cardboard shipping cartons containing FML and metal bands
First aid supplies	To provide relief from minor injuries
Portable pumps	To pump any accumulated water from supporting surface
Common tool kit (e.g., hammer, saw, etc.)	To make miscellaneous repairs, etc.
Water supply	To supply personnel drinking and equipment cooling needs
Pencil and paper	To write daily reports, etc.
Phone and/or radio communications	To provide off-site contact

- Frequency:

  - Once prior to commencement of FML placement.
  - Daily after placement and seaming operations commence.

- Documentation: The CQA inspector should maintain an accurate log in the daily diary noting the presence and workability of all equipment.

- Interpretation: All required equipment must be on site and in working condition prior to commencement of FML placement. Once FML placement begins, all equipment is to be kept in working order or replaced.

- Alternatives: None.

PERSONNEL

FML placement personnel should be well qualified and must wear appropriate clothing when placing FML sheets.

Qualifications

FML placement is generally performed using a combination of large equipment (e.g., a front-end loader) and placement crews. It is acceptable for placement crews to have only minimum initial training, provided that each crew is supervised by a qualified foreman (a person who has installed more than 93,000 square meters [1,000,000 square feet] of FML). Minimum training should consist of:

- Brief instruction on the purpose of FML installation.

- Brief instruction on placement procedures.

- Knowledge of safety procedures to be observed during FML placement, including:

  - Techniques for dismounting from an FML lifted several feet in the air during a windy day.

  - Safe methods of removing metal bands from FML packaging. Figure 5-1 illustrates how not to remove a metal band; note that the band could snap in the person's face.

  - Staying clear of FML being rolled down side slopes (see Figure 5-2).

  - Refraining from touching dark, sun-exposed FML with bare skin.

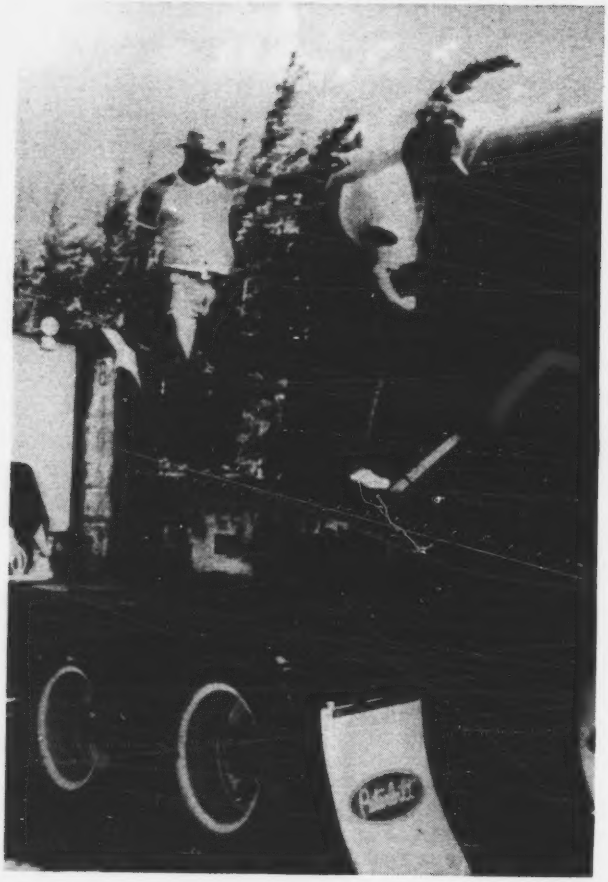

Figure 5-1. Example of how not to remove a metal band.

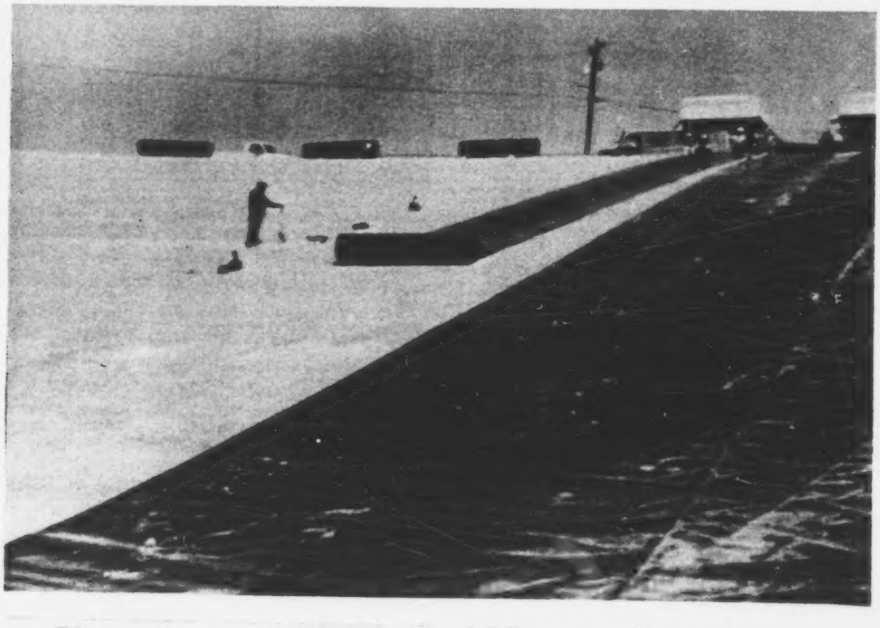

Figure 5-2. Workman standing aside while FML is rolled down side slope.

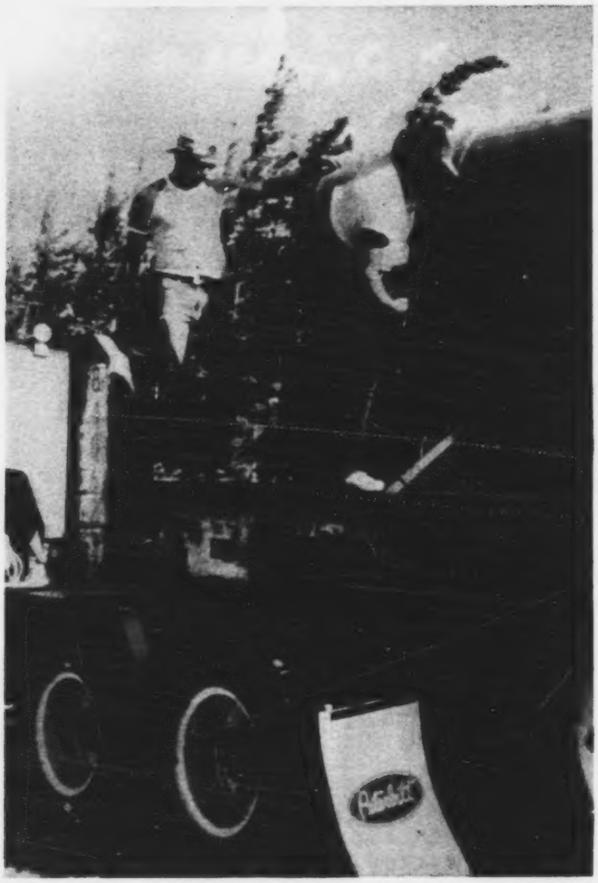

Figure 5-1. Example of how not to remove a metal band.

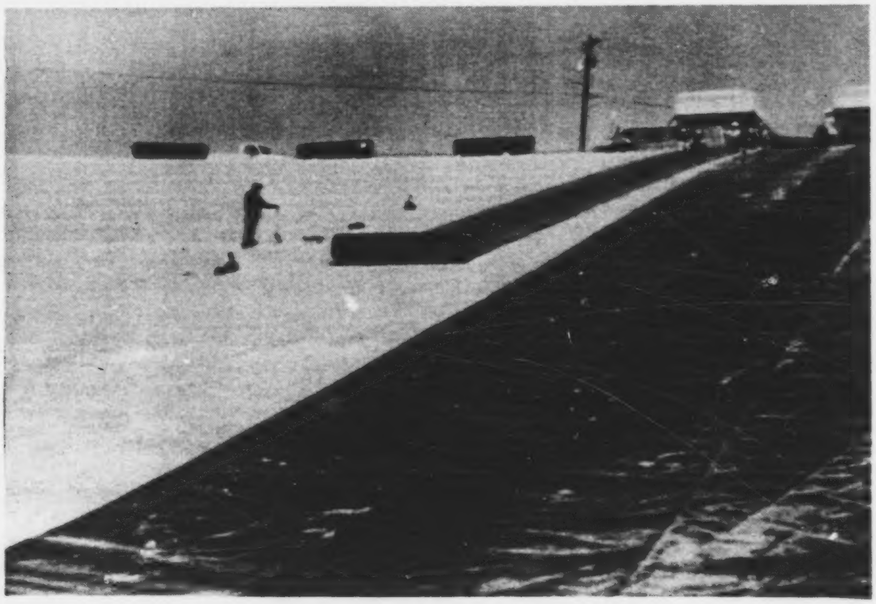

Figure 5-2. Workman standing aside while FML is rolled down side slope.

  - Awareness of techniques to be used to avoid overstressing of arms, legs, and back during placement operations.

Inspection Procedures--

- Purpose: Assurance is required that foremen and placement personnel have proper qualifications and training.

- Method: All personnel should meet the minimum experience and training requirements.

  - Foreman: Installed more than 93,000 square meters [1,000,000 square feet] of FML.

  - Placement personnel: At least the minimum training, including an understanding of the purpose of FML installation, and knowledge of placement and safety procedures.

- Frequency: An inquiry of qualifications should be made prior to personnel beginning work on placement of the FML.

- Documentation: A record of each installer, by name, should be kept in the daily diary.

- Interpretation: No foreman or placement personnel may work on the FML project without proper qualifications or training.

- Alternatives: The FML installation contractor could provide the required information to the inspector in lieu of the inspector requesting signed statements.

Clothing

All on-site personnel should be required to wear special clothing during FML placement and seaming. This includes:

- Smooth-soled shoes. No shoes with indented patterns should be worn, since rocks can become trapped in the void areas and inadvertently puncture and/or tear the FML.

- Gloves. When handling/pulling FML into place, gloves should be worn to prevent abrasion or other damage to worker hands.

Figure 5-3 depicts a worker wearing gloves and smooth-soled shoes while preparing an HDPE roll for placement.

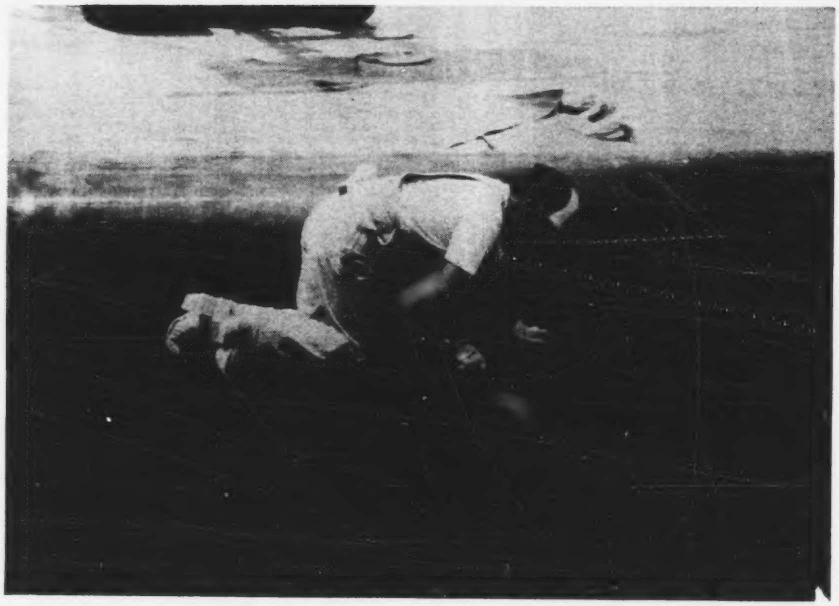

Figure 5-3. Worker wearing appropriate apparel

Inspection Procedures--

- Method: Each installer should be inspected to ensure that his clothing and footwear will not cause damage either to the FML or to himself during placement (e.g., smooth-soled shoes and gloves).
- Frequency: Each crew must be observed prior to the start of work each day.
- Location: All crews must be observed.
- Documentation: A record of each installer, by name, should be maintained in the daily diary; any unacceptable apparel should be noted.
- Interpretation: All persons handling or working on the FML should conform to the dress requirements.
- Alternatives: The liner contractor could assume responsibility for a daily check of his employees. The CQA inspector would then receive an acceptance report from the contractor and make spot observations throughout the day for noncompliance.

WEATHER CONDITIONS

The inspector should be aware that certain weather conditions will not permit the placement of FML. These include:

- Windy days. The FML may be blown around the site during severe winds, causing danger to workers (e.g., the FML being raised off the ground with workers on top of it). Strong winds might also cause the FML to whip up at the edges and ultimately shred or rip.
- Rainy or snowy days.
- Hot days. The FML can be stretched beyond repair under the stress of being placed, and the surface temperature atop the FML can be elevated beyond what is safe for placement crews.
- Days of severe cold. The FML is difficult to unfold or unroll during extremely cold weather.

Inspection Procedures

- Method: Observe weather conditions at the site for severe winds, rain, snow, and severe heat or cold.

- Frequency: Weather conditions should be observed throughout the day.

- Documentation: Wind velocities, temperatures, and moisture conditions at the site should be periodically recorded throughout the day in the daily diary.

- Interpretation: Work on the FML cannot proceed during periods of severe wind, rain, snow, and severe heat or cold.

FML LAYOUT

Every project involving the installation of an FML will have an FML sheet layout plan (see Figure 5-4) prepared that clearly shows the following information:

- Sheet layout with a number assigned to each sheet according to a logical numbering system.

- Seam locations.

- Penetration locations (e.g., inlet piping).

Prior to the placement of FML sheets, the inspector should meet with the installer to review the layout plan and strategy to avoid any problems after placement commences.

Once FML placement commences, certain placement procedures should be followed:

- Only those sheets that can reasonably be handled by the seaming crew(s) during the course of a work day are to be placed (see Figure 5-5).

- Sheets should be unfolded or unrolled in the same direction as the wind.

- Sand bags are to be placed on top of the sheets to prevent movement and damage by wind action (see Figure 5-6).

- Sheets are to be placed with specified overlap for making field seams.

Placement of the FML on the supporting surface is influenced by a variety of factors. These include:

- Type of FML.
- Thickness of FML.
- Size and configuration of facility.

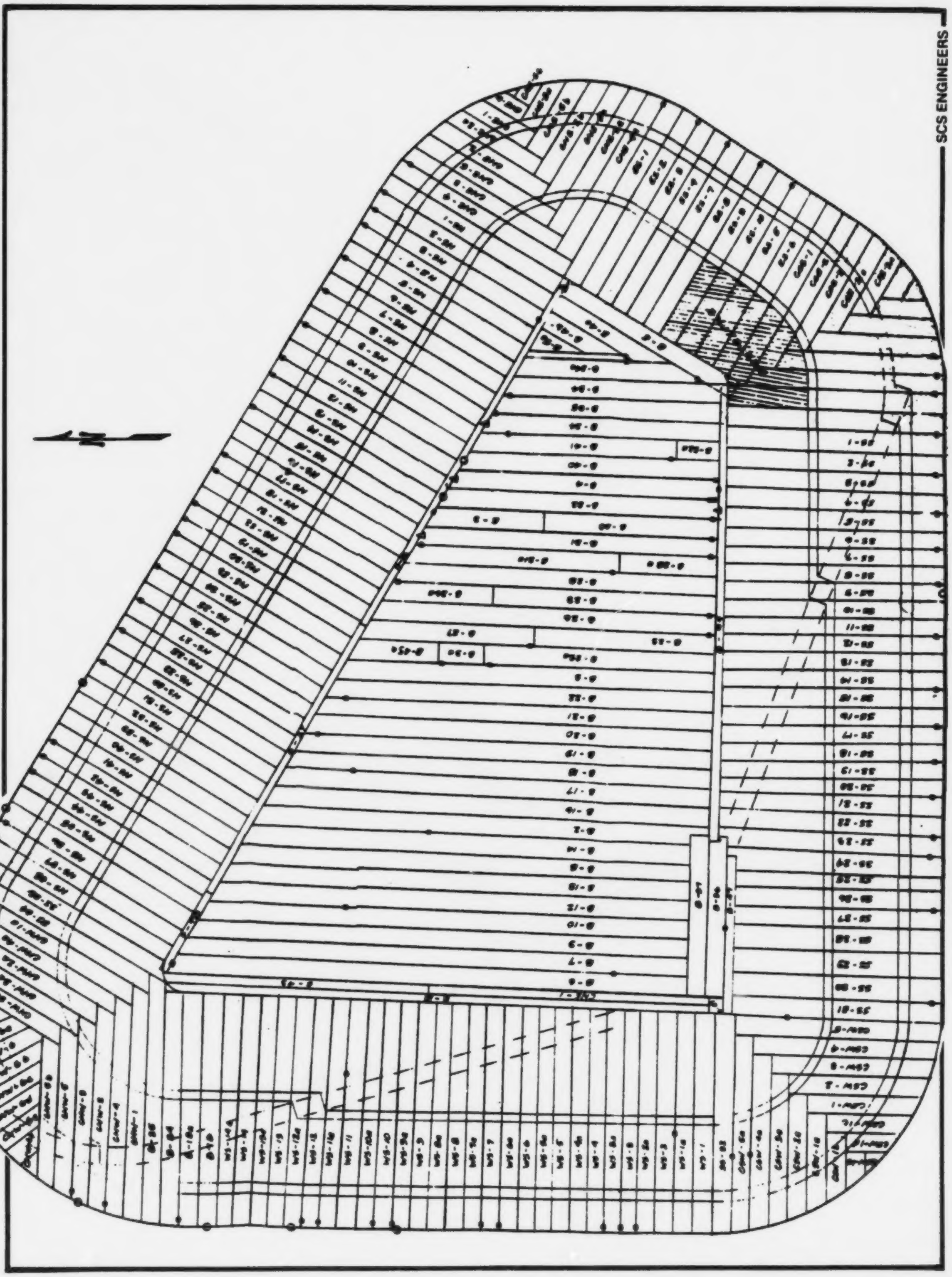
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Figure 5-4. Example FML sheet layout plan

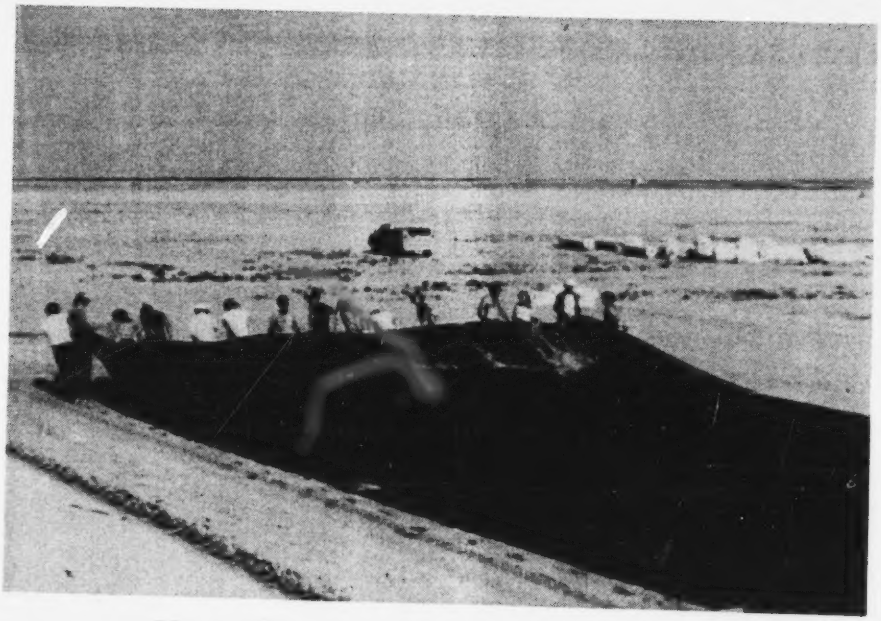


Figure 5-5. Crew placing FML sheet.

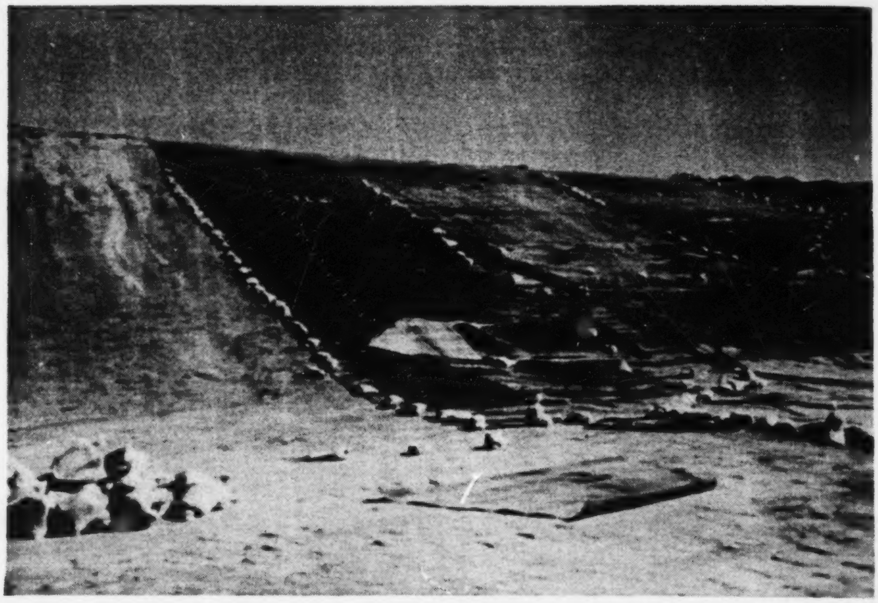


Figure 5-6. Sandbags on edge of FML.

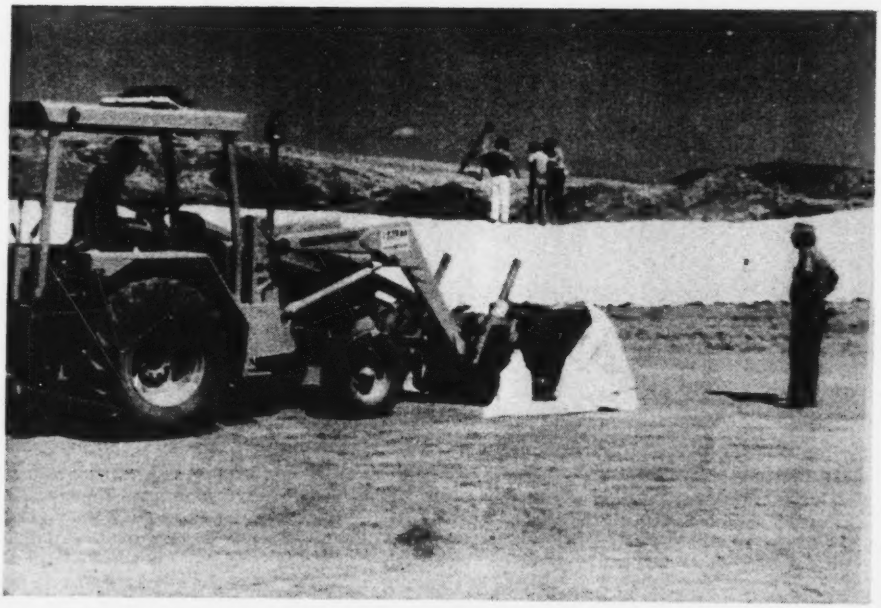


Figure 5-7. FML being transported by wheel loader

- Accessibility.
- Steepness and length of slopes.
- Location of penetrations.

A discussion of each of these factors is presented below.

Type of FML

The typical procedure for placing a folded CSPE, PVC, or CPE sheet is to transport the sheet to the location where it will be placed, unpackage it, unfold it, and position it in accordance with the sheet layout plan. Care should be taken not to drag the FML across the supporting surface during unfolding operations. Figures 5-7, 5-8, and 5-9 show an FML being transported and unfolded during placement operations.

Rolled materials such as HDPE are transported to the placement location and then unrolled on flat or gently sloping surfaces. The FML is transported and unrolled using the bucket of a front-end loader or similar equipment (see Figures 5-10 and 5-11). Care should be taken not to puncture the FML during unrolling operations. When unrolling FML down slopes, precautions are necessary to avoid injuring workers near the bottom of the slope (see Figure 5-2).

Thickness of FML

FML thickness affects sheet placement as follows:

- Thicker materials generally have smaller sheet sizes, requiring placement of more sheets than for thinner materials.

- Thicker FML sheets are heavier, sometimes requiring more equipment and manpower to place than the same size thinner sheets.

- Most FML manufacturers limit sheet weight to 1,800 kilograms (4,000 pounds).

Size and Configuration of Facility

Facility size and configuration affect FML placement in the following ways:

- Large sites are generally easier for FML placement than small sites due to the available work area.

- Odd-shaped sites require more planning with regard to FML placement, since most sheets are rectangular and require cutting to conform to odd shapes.

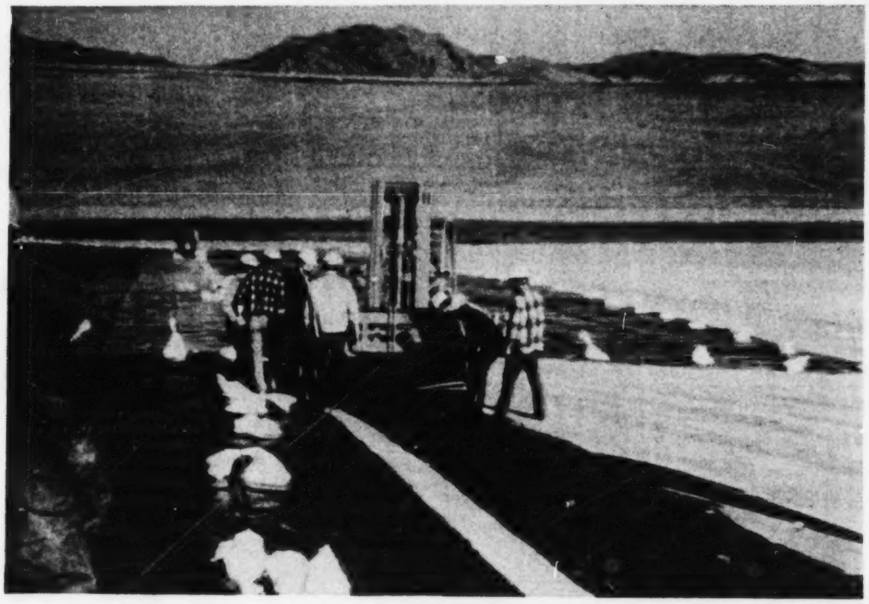


Figure 5-8. FML being unfolded from forklift.

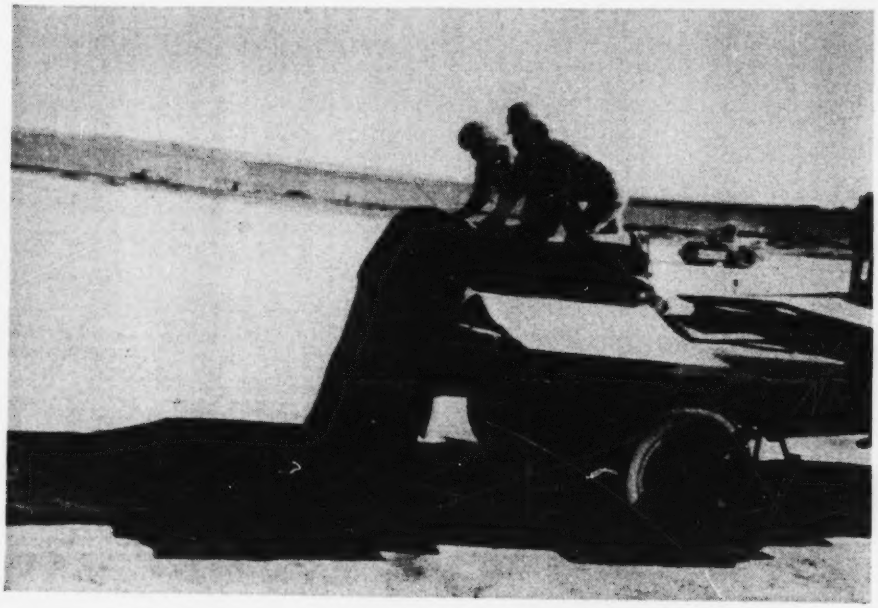


Figure 5-9. FML being unfolded from truck.

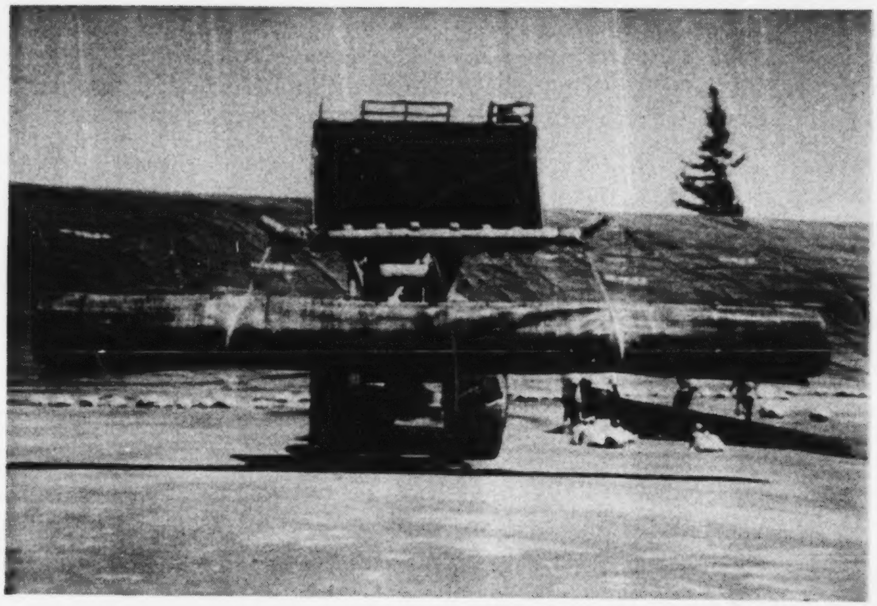


Figure 5-10. FML roll being transported by wheel loader

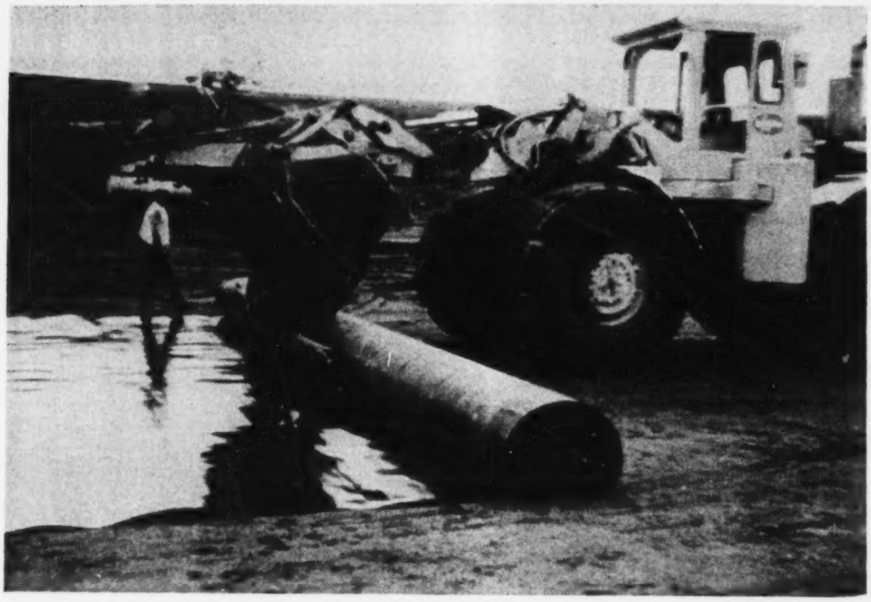


Figure 5-11. FML being spread by front loader

Accessibility

Accessibility to and around the area where FML sheets are to be placed is important. Critical placement areas are located at the top and bottom of slopes. A working area at least 3 meters (10 feet) wide should be provided at the top of a slope on the berm to provide ample working space for placing the sheets on the slope (see Figure 5-12). Ample working space is also required at the bottom of the slope and on the bottom of the area to permit efficient placement of the sheets (see Figure 5-13). Sometimes a ramp is provided for access to the bottom of the slope.

Placement on Slopes

Placement of FML on slopes requires special attention. In all cases:

- Horizontal seams should be avoided or minimized on steep slopes. Seams made on sheets placed in this position are susceptible to failure. Figure 5-14 shows proper seam positioning on slopes.
- Foot traffic must be restricted on the FML after it has been placed on a slope. Ladders should be used where possible.

Placement of FML sheets on slopes steeper than 2:1 (horizontal to vertical) is more difficult, since steep slopes cannot be easily traversed by placement personnel. Ladders or similar equipment must be used. Considering earthwork and FML installation requirements, the best average slope is 3:1

Generally, FML sheets should be long enough to extend the entire slope length and out onto the bottom (see Figure 5-13), so that lateral seams do not have to be made on the slope.

Placement Around Penetrations

FML sheets should be placed around penetrations (e.g., structures, pipes) in such a manner that the FML sheet can be attached/anchored directly to the penetration. The location of all penetrations and placement details at the penetration should be shown on the sheet layout plans.

Inspection Procedures

- Method: Observations are made of:
  - Equipment used for placement of the FML on the supporting surface.

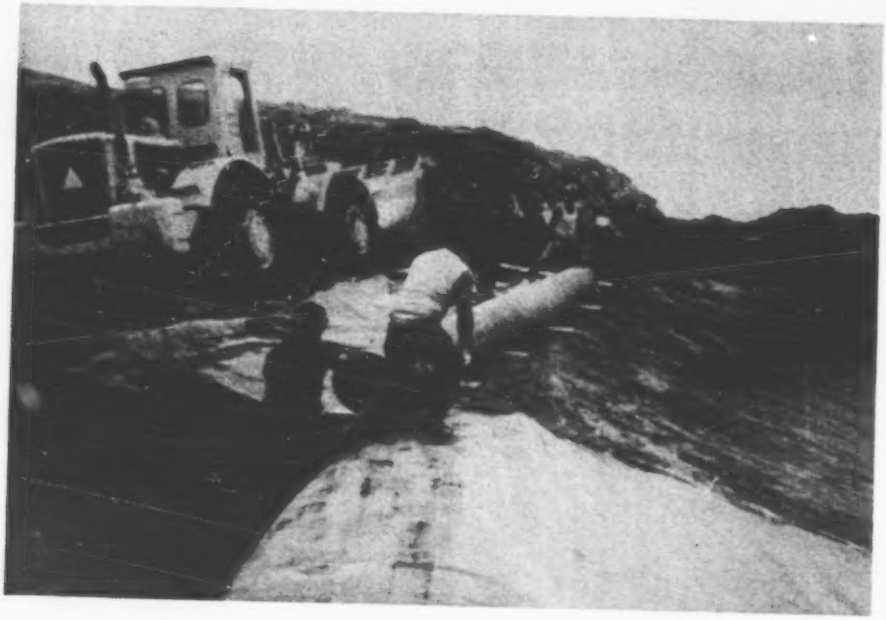


Figure 5-12. Acceptable working area at top of slope.

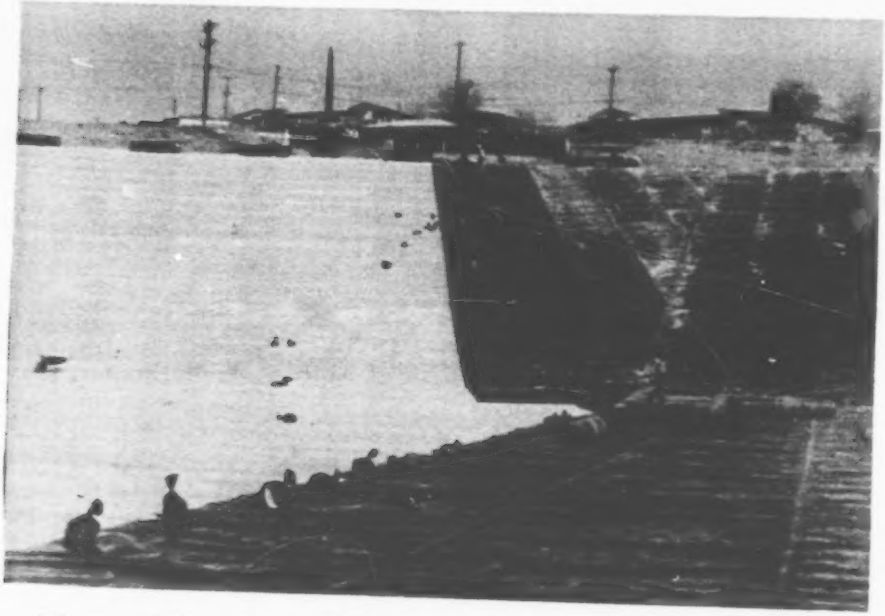


Figure 5-13. Acceptable working space at bottom of slope

Figure 5-14. Properly placed FML on side slope

- FML placement on supporting surface as follows:
    - -- Only those sheets that can reasonably be seamed by the seaming crew(s) during the course of a work day are placed.
    - -- FML sheets are unfolded or unrolled in the same direction as the wind.
    - -- Sand bags are placed on in-place FML sheets to prevent movement and damage by wind action.
    - -- FML sheets are placed with specified overlap for field seams.
    - -- Crew size and clothing are adequate.
    - -- Safety procedures are followed.

    Each sheet must be walked in such a way that the entire surface, including factory seams, is visually inspected. For FMLs that are factory-fabricated from roll stock widths, the normal procedure is to walk the length of each roll stock width and inspect for defects including punctures, bubbles, etc, as well as observing the seam on one side at the same time. FMLs with defects are to be marked for repair using a yellow non-wax crayon marker.

- Frequency: Ongoing observation.

- Location: All FML sheets and factory seams are inspected.

- Documentation: The inspector should record observations as well as routine information (such as date, time, weather, equipment, personnel, and construction location) in the daily diary. Notes should also be maintained on a print of the sheet layout to monitor the sheets that have been placed and inspected. Observations to be documented include the following:
    - Quality of material and placement procedures. A detailed description should include the following information:
        - -- Defects encountered.
        - -- Location and designation number of each FML sheet placed.

  - Equipment and personnel utilized.
  - Delays and problems encountered.
  - CQC procedures used.

- Interpretation: Only materials which meet the specifications and are of acceptable quality should remain in place. Damaged FMLs or defective seams should be repaired or replaced, as applicable.

CHAPTER 6

SEAMING OPERATIONS

INTRODUCTION

Seaming is a critical step in an FML installation. FML seams can be prepared either in the factory or the field. Factory seams are manufactured in a controlled environment, and seam quality is generally superior to field seams. Since the inspector is not responsible for observing the manufacture of factory seams, only a brief summary of factory seaming techniques is provided in this chapter.

The primary objective of this chapter is to discuss field seaming operations and the inspection thereof. However, the discussion is necessarily general, because each FML manufacturer/fabricator has specific (and often proprietary) seaming equipment and seaming procedures. Prior to the start of FML seaming operations, the manufacturer should provide the inspector with precise specifications on the equipment and procedures that will be used to seam their material in the factory and field. In addition, the inspector should meet with a representative of the manufacturer/fabricator for an explanation and demonstration of the seaming equipment and procedures to be used on the job.

SEAMING METHODS

Several methods are available for seaming an FML, whether in the field or the factory, including:

- Liquid-applied solvent or adhesive methods:

  - Solvent bonding.
  - Bodied solvent adhesive.
  - Solvent adhesive (solvent cement).
  - Contact adhesive.

- Thermal methods:

  - Hot air.
  - Hot wedge (hot knife).
  - Dielectric (electronic bonding).
  - Extrusion (fusion) welding.

- Vulcanizing tapes and adhesives.

- Tape and mechanical seaming.

A brief description of each of these seaming methods is given in Table 6-1. Figures 6-1 through 6-3 illustrate several of the most commonly used methods.

Factory Seams

Generally, factory seams are lap joints. However, butt joints are sometimes used for repair of FML in the factory.

The methods used for factory seaming PVC, CSPE, and CPE are as follows:

- Solvent bonding.
- Dielectric.
- Thermal (hot air).

Seam bond is generally 2 centimeters (3/4 inch) minimum for PVC and 4 centimeters (1-1/2 inches) minimum scrim-to-scrim for CSPE and CPE, with no free edges.

HDPE is generally factory-seamed by fusion welding. Seam bond is normally 2.5 centimeters (1 inch).

Field Seams

Field seams for PVC, CSPE, and CPE are almost always solvent-bonded lap joints. However, butt joints are sometimes used (Figure 6-4 shows a typical lap and butt joint for CSPE FML). The solvents used vary with FML type and manufacturer. No sophisticated equipment is used in the field; all of the work is performed by hand using simple tools and materials. PVC field seams should be at least 5 centimeters (2 inches) wide with no free edges. CSPE and CPE field seams should be at least 10-centimeter (4-inch) wide scrim-to-scrim overlap with 7.5-centimeter (3-inch) minimum width of adhesive and with no free edges.

HDPE field seams are always lap seams formed by thermal methods: hot air, hot wedge, and extrusion welding. Seam overlap is generally 10 centimeters (4 inches).

Tables 6-2 and 6-3 summarize pertinent seaming information for each FML type.

EQUIPMENT

A general list of equipment required for FML seaming operations is provided in Table 6-4. Figures illustrating equipment being used for field seaming operations are contained throughout the chapter.

TABLE 6-1. SEAMING METHODS

Seaming Method	Description
Liquid Applied Solvent or Adhesive Systems	
• Solvent Bonding	• A solvent recommended by the FML manufacturer is applied between the two FML surfaces to be bonded and a pressure applied to the seam area. The solvent softens the surfaces to be bonded creating the "bond" and then evaporates. Seaming should generally be accomplished when sheet and adhesive temperatures are above 15.5°C (60°F). At lower temperatures auxiliary means of surface area heating such as heat guns or portable radiant heaters must be used.
• Bodied Solvent Adhesive	• A bodied solvent adhesive is prepared by dissolving approximately 8 to 12 percent of the liner compound in the solvent recommended by the FML manufacturer. The seaming technique is the same as for solvent bonding.
• Solvent Adhesive (Solvent Cement)	• A liquid-applied solvent adhesive is used to develop bond strength between two sheets by means of an adherent left after dissipation of the solvent. The adhesive becomes an additional element in the seam system effecting a surface-to-surface bond but not a homogeneous bond. Sufficient rolling pressure must be applied to produce an acceptable adhesion.
• Contact Adhesive	• Usually applied by brush or roller to both lining surfaces to be joined. After the adhesive has attained the proper degree of tackiness, the two surfaces are immediately joined together. The use of this type of adhesive requires careful alignment of the FML material before bonding because the joined surfaces should not be realigned after assembly. After joining, the seam should be rolled with a steel or plastic roller in a direction perpendicular to the edge of the seam. The adhesive forms a bond and remains as an additional element within the seam.

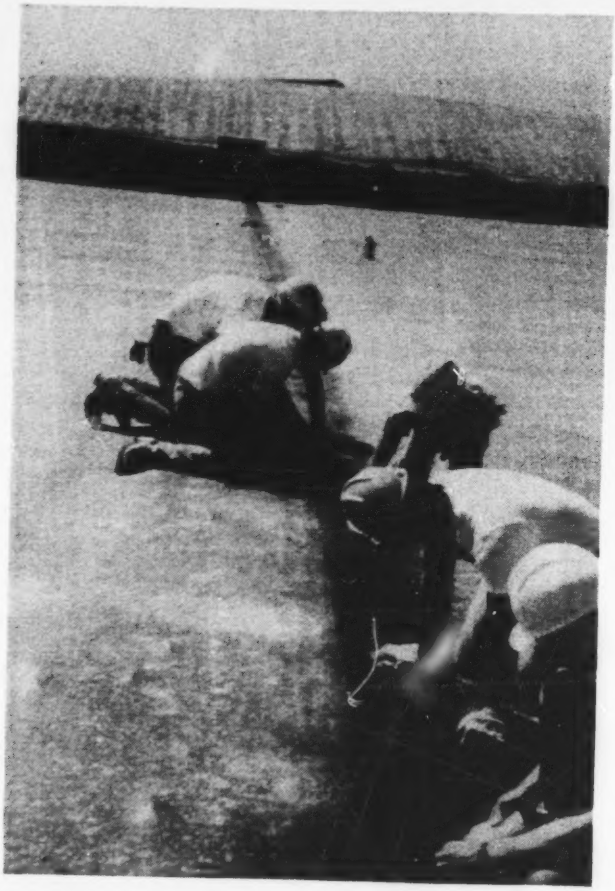
TABLE 6-1 (continued)

Seaming Method	Description
Thermal Methods	
• Hot Air Methods	• A machine consisting of resistance heaters, a blower, and temperature controls directs a blast of hot air or gas usually in excess of 260 °C (500 °F) between two polymer sheets materials, thus melting the surfaces. Immediately following the surface melt, pressure (usually by roller is applied to bond the area to form a homogeneous seal between the two membrane at the seam overlap. The heat-producing machine can be either a hand-held unit for the field or a large, automated factory machine with preset controls for temperature, movement rate, and roller pressure.
• Hot Wedge (Hot Knife)	• Consists of a hot electrically heated resistance element in the shape of a blade or V-shaped wedge that is passed between the two sheets to be sealed and in intimate contact with them, thus melting the surfaces. Immediately following the melting, roller pressure is applied effecting a homogeneous bond. Single hot wedge and dual hot wedge systems are presently available. The dual hot wedge weld forms a continuous air channel between the two welded seams which is used for testing the bond continuity by injecting air pressure. Welding rate (movement of the machine) as well as temperature and roller pressure are adjustable and continuously monitored.
• Dielectric (Electronic Bonding)	• Used on thermoplastic and thermoplastic elastomer materials and is carried out only in a fabrication plant.
• Extrusion (Fusion) Welding	• Consists of extruding a ribbon of molten polymer of HDPE resin (extrudate) between or at the edge of two overlapped HDPE sheets. Extrudate placed between two overlapped sheets is referred to as flat welding. Extrudate placed at the edge of a seam is called a fillet or hand extrusion weld. The fillet-type weld area may or may not preheated with hot air.

TABLE 6-1 (continued)

Seaming Method	Description
Vulcanizing Tapes and Adhesive	• An uncured tape or adhesive containing the polymer base of the liner and cross-linking agents (usually sulfur or sulfur-bearing compound) is placed between the overlaps of two curd (vulcanized) elastomer sheets. Upon application of heat and pressure at the seam area, molecular cross linking (vulcanization) of the polymer base in the tape occurs, thus achieving a bond strength between the two sheets not attainable with ordinary adhesives. Factory vulcanizing press or an autoclave, whereas field seams can be fabricated using the uncured tape and a portable seaming machine that provides the necessary heat and pressure with a bar.
Tape and Mechanical Seaming	• Made by applying an adhesive-backed strip between or at the edge of two sheets providing tensile strength to the joint.

Source: Evaluation of Flexible Membrane Liners Seams, Draft Report, U.S. Bureau of Reclamation Engineering and Research Center.



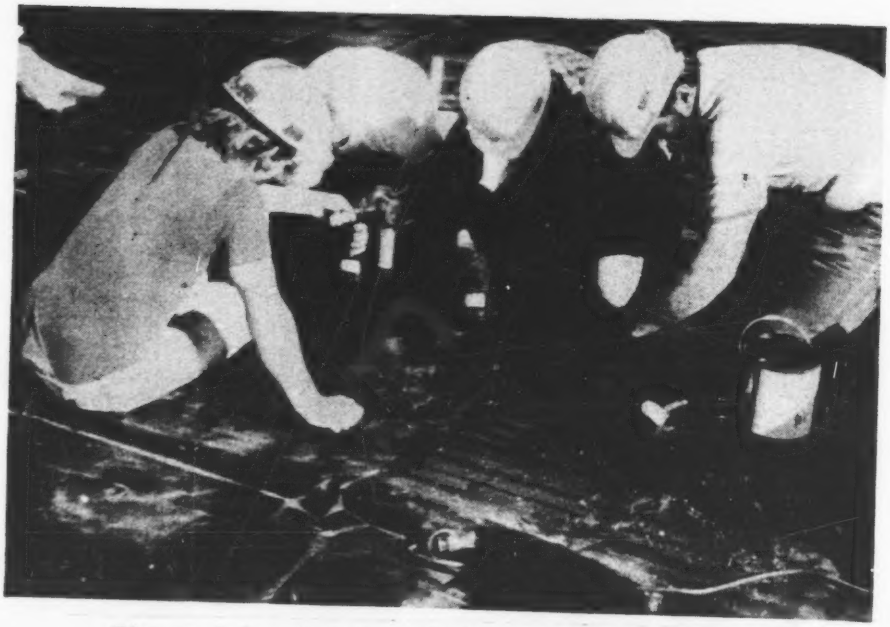


Figure 6-1. Seaming of FML using liquid-applied solvent/adhesive.

Figure 6-2. Seaming of FML using hot air.

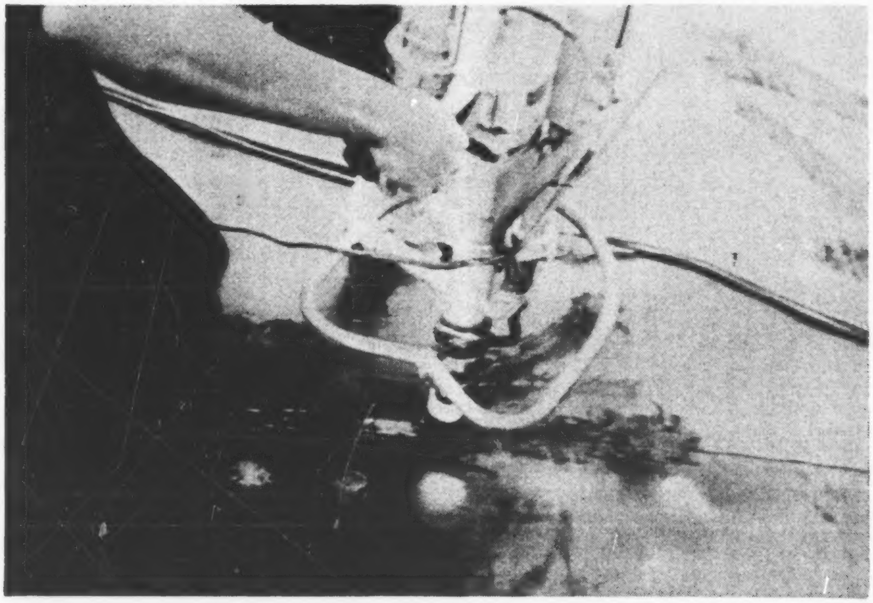


Figure 6-3. Seaming of FML by extrusion (fusion) welding.

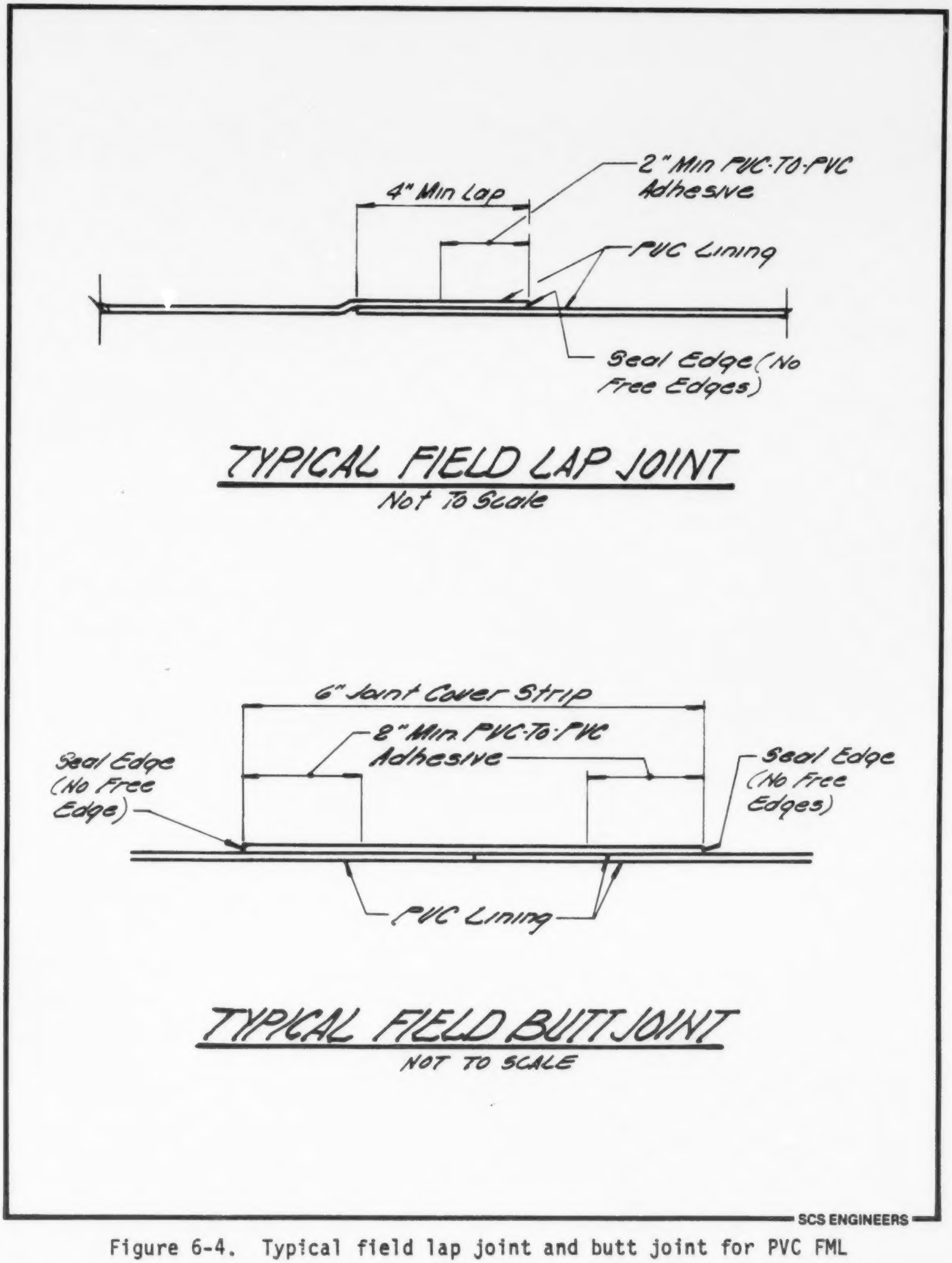

2" Min PVC-TO-PVC Adhesive
4" Min Lap
PVC Lining
Seal Edge (No Free Edges)
TYPICAL FIELD LAP JOINT
Not To Scale
6" Joint Cover Strip
2" Min. PVC-To-PVC Adhesive
Seal Edge (No Free Edge)
Seal Edge (No Free Edges)
PVC Lining
TYPICAL FIELD BUTT JOINT
NOT TO SCALE

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Figure 6-4. Typical field lap joint and butt joint for PVC FML

TABLE 6-2. FACTORY AND FIELD SEAMING TECHNIQUES FOR EACH FML TYPE

	FML Type			
Seaming Technique	PVC	CPE	CSPE	HDPE
Solvent Bonding	*/‡	*/‡	*/‡	
Bodied Solvent Adhesive	‡	‡	‡	
Solvent Adhesive (Solvent Cement)	‡	‡	‡	
Contact Adhesive	‡	‡	‡	
Hot Air	*/‡	*/‡	*/‡	*/‡
Hot Wedge (Hot Knife)				*/‡
Dielectric (Electronic Bonding)	*	*	*	
Extrusion (Fusion) Welding				*/‡
Autoclave (Heat & Pressure)				
Vulcanizing Tapes and Adhesives				
Tape and Mechanical Seaming	‡	‡	‡	

* Factory seaming technique.
‡ Field seaming technique.

TABLE 6-3. LAP SEAM BOND REQUIREMENTS*

FML Type	Minimum Seam Bond (Inches)‡ Factory	 Field
PVC	3/4	2
CSPE	1-1/2	3
CPE	1-1/2	3
HDPE	1	1

* Lap seam bond is different from lap seam overlap. Generally, FMLs are overlapped more than bonded, particularly in the field. Also, FMLs with scrim must be overlapped and bonded according to scrim width.

‡ 1 inch = 2.54 cm.

TABLE 6-4. EQUIPMENT REQUIRED DURING FML SEAMING OPERATIONS

Item	Use
Scissors (bright-colored with rounded points)	To cut FML materials
Sandbags	To secure unseamed FML panels to prevent damage by wind
Electric generator and extension cords	To operate heat guns, power tools, and lights.
Scrub brushes	To clean FML prior to seaming, patching, anchoring
Fuel	To operate gasoline and/or diesel equipment
Extra pieces of FML	To use as a tarp to store materials on the seaming area, and for patches
Ladders	For working on slope
Seaming equipment:	
- Tape	For measuring
- Clean bristle brushes 7.5 cm (3 inches) wide x 10 cm (4 inches) long, squeeze bottles, caulk guns	To apply adhesive, cement, solvent caulk, etc.
- Hand rollers	To apply pressure to seam after application of adhesive, cement, and solvent
- Clean, absorbent white cotton rags	To clean FML in area of seam and to wipe excessive adhesive
- 10-cm (4-inch) dia plastic funnel	To assist in pouring adhesives and solvents from one container to another
- 3.785-liter (1-gallon) polyethylene pails	To hold adhesives and solvents
- Wood boards	To provide support under FML during seaming operations
- Heat guns	To warm FML during seaming operations

TABLE 6-4 (continued)

Item	Use
- Heat sealing equipment	Commonly used on HDPE, sometimes used on other FML types
- Grinding equipment	For preparation of HDPE seams
- Fusion welding equipment	For HDPE seaming
First aid supplies	To provide relief from minor injuries
Mechanics tool kit	To make miscellaneous repairs
Water supply	To supply personnel drinking and equipment cooling needs
Phone and/or radio communications	To provide off-site contact
Fire extinguishers	Use for fires

Inspection Procedures

- Method: Observe all equipment to be used for seaming operations to ensure that the required types and quantities are on site. Have installer's representative explain and demonstrate the seaming equipment. Ensure that all equipment is in working order prior to commencement of seaming operations each day.
- Frequency:

  - Once prior to commencement of FML seaming operations.
  - Daily after seaming operations begin.
- Documentation: The inspector should maintain an accurate log in the daily diary noting the presence and workability of all equipment.
- Interpretation: All required equipment must be on site and in working condition prior to commencement of FML seaming operations. Once FML seaming begins, all equipment is to be kept in working order or replaced.
- Alternatives: None.

PERSONNEL

Each field seaming crew should be comprised of a sufficient number of experienced persons to properly carry out seaming operations. Each crew member should wear clothing that will not damage the FML during seaming operations.

Crew Size

For PVC, CSPE, and CPE, a typical crew is comprised of four individuals:

- One cleaner.
- One washer.
- One solvent/adhesive applier.
- One roller.

If necessary, cleaning and washing can be performed by the same crew member.

For HDPE, the following crew size is appropriate:

- One cleaner.
- One grinder.
- One welder.

If necessary, cleaning and grinding can be performed by the same crew member.

On many jobs, two or more seaming crews will be used. One inspector should be provided for each seaming crew. Multiple crews should work in opposite directions to prevent the formation of "fishmouths" (see Figure 6-5), and should be spaced as far apart as possible to prevent unnecessary conversation.

Experience

Each project should have a seaming supervisor who is responsible for all seaming crews. The supervisor and all crew foremen should meet the following minimum installation experience requirements for FMLs:

- Seaming supervisor - 93,000 square meters (1 million square feet) of FML placed and seamed.
- Crew foreman - 9,300 square meters (100,000 square feet) of FML placed and seamed.

As a minimum, all crew members should have the following training:

- Brief instruction on the purpose of FML installation.
- Completion of a training course in seaming operation including seaming techniques on side slopes (slope ladders should be used so that no one stands directly on the FML).
- Knowledge of proper clothing to wear while working on the FML (see Clothing subsection).

Inspection Procedures--

- Purpose: Assurance is required that all seaming personnel have proper qualifications and training.
- Method: All personnel should complete a signed statement confirming that they meet minimum experience/training requirements.
- Frequency: Each worker should be tested prior to the beginning of work.
- Documentation: A record of each seaming crew member and supervisor, by name, should be kept in the daily diary.

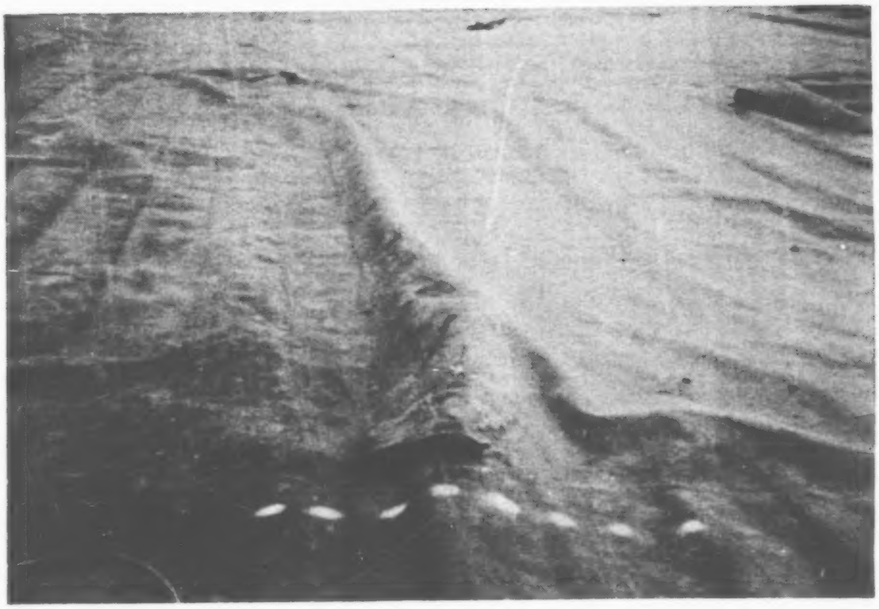


Figure 6-5. A "fishmouth" that has been torn along its edges

- Interpretation: No person without proper experience should work on the FML project without proper qualifications or training.

- Alternatives: The FML installation contractor could provide the required information to the inspector in lieu of the inspector requesting signed statements.

Clothing

All seaming crews should wear the following special clothing during FML seaming operations:

- Smooth-soled shoes. No shoes with indented patterns should be worn, since rocks can be trapped in the void areas and inadvertently puncture and/or tear the FML.

- Gloves. When applying solvent/adhesive to FML, latex or other type gloves should be worn to prevent irritation to hands. Figure 6-6 depicts workers wearing latex gloves during solvent/adhesive application. Leather gloves help protect crew members' hands from inadvertent contact with hot seaming equipment (e.g., hot air guns) or other damage. Crew members should refrain from touching dark, sun-exposed FML with their bare skin.

- Knee pads. Knee pads are helpful in protecting workers' knees during seaming operations.

Inspection Procedures--

- Method: All seaming and auxiliary personnel should be inspected to ensure that their clothing (including footwear) is of the type that would not damage the FML (e.g., smooth-soled shoes). The seaming crew should also be required to wear personnel protective equipment (e.g., gloves) during FML seam installation.

- Frequency: Each crew member and all auxiliary personnel must be observed to meet dress and safety requirements prior to the start of each work day.

- Documentation: A record of each crew member, by name, should be maintained in the daily diary, along with a notation regarding conformance with pertinent requirements.

- Interpretation: All persons walking on or seaming FML should conform to dress and safety requirements.

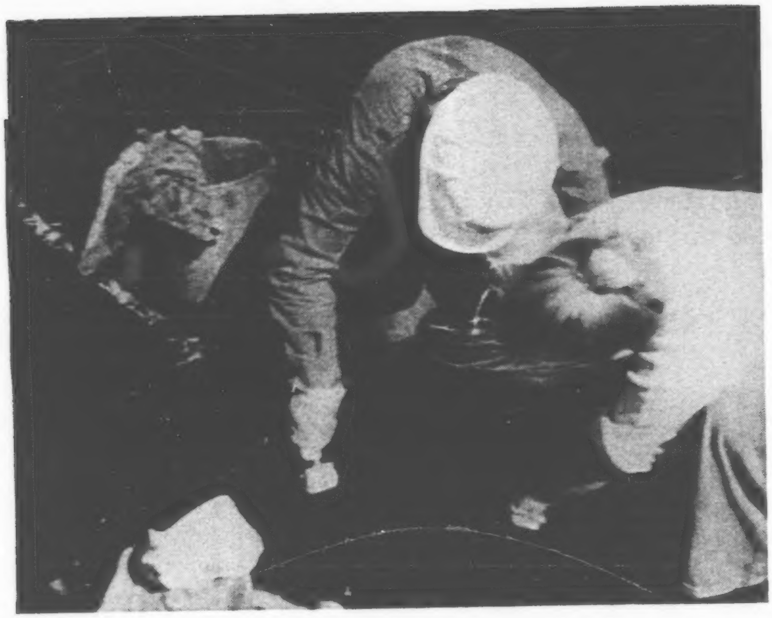


Figure 6-6. Workers seaming with solvent/adhesive using latex gloves

- Alternatives: The liner contractor could assume responsibility for a daily check of his employees. The CQA inspector would then receive an acceptance report from the contractor and make spot observations throughout the day for noncompliance.

ENVIRONMENTAL CONDITIONS

Generally, FMLs should not be field-seamed under adverse weather/environmental conditions. In some cases, protective measures can be taken to nullify these adverse conditions (e.g., construction of wind breaks). The type of FML will dictate the type of protective measures taken.

Adverse weather/environmental conditions include:

- High wind. High winds may stretch the FML, causing wrinkles and other distortions, or may move the FML out of position. High winds can also cause solvents to dry prematurely, creating an inferior seam bond.
- Rain/moisture. PVC, CSPE, and CPE seaming operations cannot proceed in wet/moist conditions caused by rain, snow, or heavy mist, because the solvent is affected by moisture bond. It is also difficult to obtain a satisfactory fusion weld during rain, since the amount of heat being applied to the weld could be altered.
- Hail. Hail is capable of damaging an FML after it is in place. Consequently, after a hail storm, all exposed FML should be checked for damage and repaired as necessary.
- High or low temperatures. Most FML manufacturers have recommended minimum and maximum temperatures for seaming FML. If seams are formed outside these temperature ranges, the integrity of the seam is questionable. The FML manufacturer should be contacted for recommended seaming temperatures.
- Dust. Dust can form a coating on the FML surface, affecting the ability of the solvent/adhesive to properly bond the FML at the seam area. The presence of dust can sometimes be reduced through the application of water to the supporting surface and the localized surrounding area.

Adverse environmental conditions can also have an effect on the attitude of the seaming crews. Unduly cold, hot, wet, windy, or dusty conditions will cause workers to divert their attention from seaming operations and often result in seams that have not been formed with proper care (e.g., insufficient effort dedicated to cleaning the bonding surface).

Inspection Procedures

- Method: Observe weather conditions at the site for high winds, rain, snow, hail, heavy mist, dust, and severe heat or cold.

- Frequency: Weather conditions should be observed throughout the day.

- Documentation: Wind velocities, temperatures, moisture conditions, and the undue presence of dust should be periodically recorded throughout the day in the daily diary.

- Interpretation: FML seaming cannot proceed during severe environmental conditions.

SEAMING

Although seaming methods vary according to FML type and manufacturer specifications, there are certain standard practices pertinent to all seaming procedures that must be followed in order to form satisfactory seams. These procedures apply to seaming of sheets and patches, and include the following:

- The working area should be clean and smooth and have adequate room for maneuvering. For solvent-bonded or other similar seams that require pressure during formation, a hard flat surface is necessary to provide adequate support for pressure application. A board is often used for this purpose.

- With PVC, care must be taken not to apply too much solvent/adhesive. Conversely, with CSPE and CPE, a liberal application of solvent/adhesive is desirable.

- Proper seam overlap is required to ensure a strong bond. Seam overlap dimensions should be provided in the specifications. Table 6-2 provides generally accepted seam overlap dimensions for each FML type. The dimensions given apply to sheets and patches.

- Sandbags should remain placed on all FML sheets and edges until the FML is covered. Sandbags should be spaced no more than 1.8 to 2 meters (5 to 6 feet) apart on edges.

- When seaming on slopes, ladders should be used, so that workers do not walk directly on the FML. It is important that workers avoid walking on in-place FML on slopes because of the tendency to dig their feet into the slope for support. This can cause depressions in the supporting surface and future stress on the FML.

- Prior to seaming an FML sheet or patch, all edges should be free of defects such as blisters and tears. Once the seam is formed, there should be no free edge on the upper FML, because equipment or other items can catch on or snag the free edge, potentially destroying the seam at that location. This ideal cannot always be attained however, since some FML manufacturers' seaming techniques actually specify a free edge at the seam. Figure 6-7 shows a typical FML patching operation.

- Seaming techniques may vary during the day depending on ambient air temperatures. For example, for solvent adhesive seams, the FML temperature in the area of the seam may need to be heated, using a heat gun or other means, during colder early morning or late afternoon hours.

Inspection Procedures

- Purpose: Inspection is required to ensure that field seams are properly prepared.

- Method: Each seaming operation should be visually inspected to ensure the following:

  - Sheets and/or patches are properly positioned and have sufficient overlap for seaming.

  - Sandbags are in place as required.

  - There are no edge defects on the sheet or patch to be seamed.

  - The working area is satisfactory for seam preparation.

  - Proper seaming techniques are being followed.

- Frequency: Ongoing inspection is required.

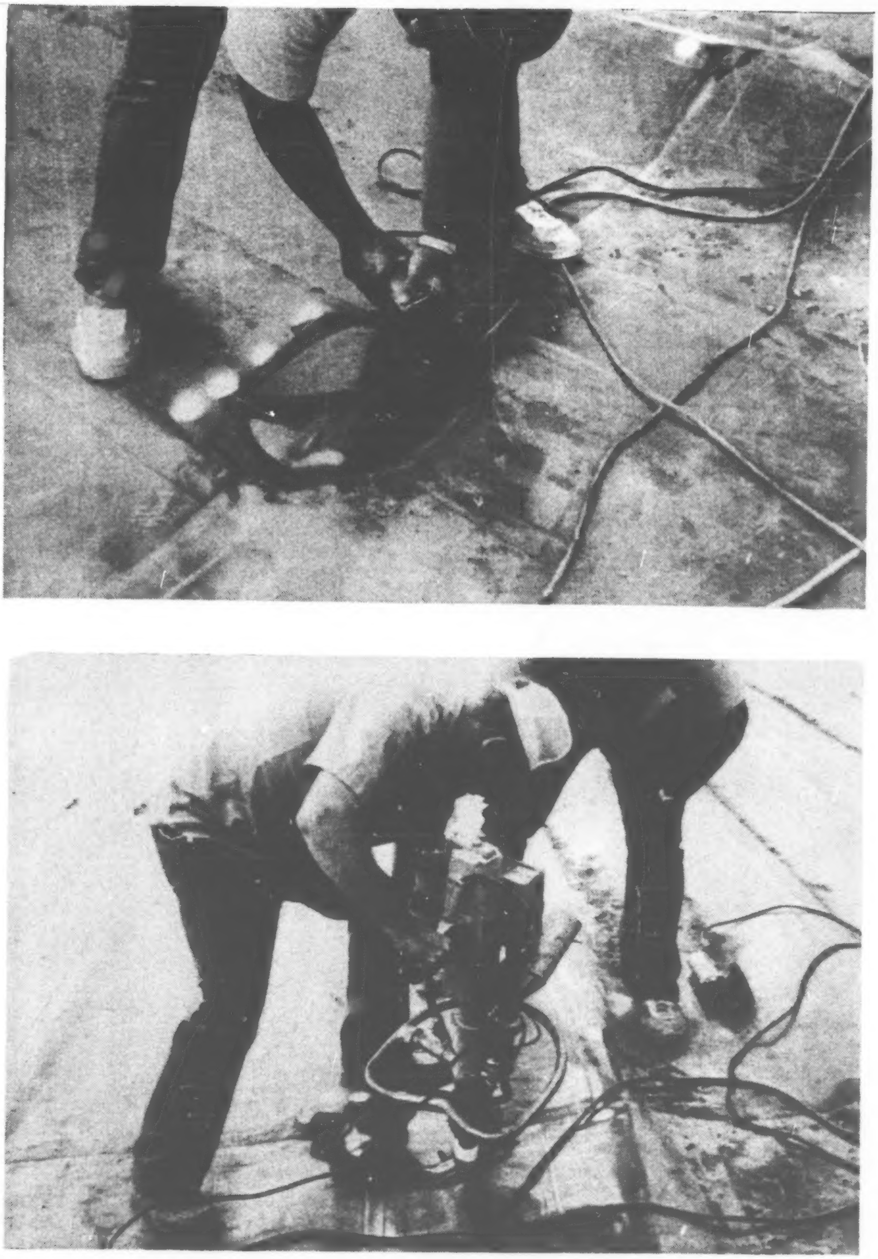


Figure 6-7. Typical patching operation.

CHAPTER 7

LINER ANCHORS/ATTACHMENTS

INTRODUCTION

One of the most common sources of failure in an FML installation occurs at the attachment of the FML to another surface. In general, these attachments consist of perimeter anchors or attachments to structures, such as pipes or columns, within the facility. Failure of a perimeter anchor can lead to seam failure or to the collapse of major portions of an FML installation. The failure of attachments within a facility will inevitably result in significant leaks. Consequently, it is essential that the anchor/attachment be properly designed and installed.

In addition to the guidance given below on specific types of anchors/attachments, there are several general practices and procedures that should be followed:

- Do not use wood battens (refer to the discussion of battens and bolts in the Anchors/Attachments subsection of this chapter).
- Do not use percussion driven fasteners.
- Attach every FML on a plane with itself, not perpendicular to the plane of the FML.
- Ensure that placement equipment is on site and in working order, and that a sufficient number of qualified placement personnel are on site.

PLACEMENT EQUIPMENT

Various types of large construction and hand-held equipment may be required for the different types of FML anchors/attachments. Figures showing examples of equipment used for FML anchoring/attaching are provided throughout the chapter.

Inspection Procedures

- Method: Observe all anchor/attachment installation equipment to ensure that appropriate types and quantities are on site. Observe the check-out of equipment to ensure that each item is in proper working order.

- Frequency:

  - Once prior to commencement of anchor/attachment installation.

  - Daily after anchor/attachment operations commence.

  Documentation: The CQA inspector should maintain an accurate log in the daily diary, noting the presence and workability of all equipment.

- Interpretation: All required equipment must be on site and in working condition prior to commencement of anchor/attachment installation. Once installation begins, all equipment is to be kept in working order or replaced.

PERSONNEL

Qualifications

In general, FML anchor/attachment installations should be performed by workers who are experienced in such work.

Inspection Procedures--

- Purpose: Assurance is required that foremen and anchor/attachment personnel have proper qualifications and training.

- Method: All personnel should complete a signed statement confirming that they meet minimum experience/training requirements.

- Frequency: An inquiry of qualifications should be made prior to personnel beginning work on anchoring/attaching of the FML.

- Interpretation: No foremen or other personnel should work on anchoring/attaching the FML without proper qualifications or training.

- Alternatives: The FML installation contractor could provide the required information to the inspector.

Clothing

All on-site personnel should be required to wear special clothing during any FML work. This includes:

- Smooth-soled shoes. No shoes with indented patterns should be worn, since rocks can become trapped in the void areas and inadvertently puncture or tear the FML.

- Gloves. When handling/pulling FML into place, the worker should wear gloves to prevent abrasion or other damage to his hands.

Inspection Procedures--

- Method: Personnel should be inspected to ensure that clothing and footwear are of the type that would not damage the FML or injure the installer (e.g., smooth-soled shoes and gloves).
- Frequency: Each crew must be observed prior to the start of each work day.
- Location: All crews should be observed.
- Documentation: A record of each installer, by name, should be maintained in the daily diary; all unacceptable apparel should be noted.
- Interpretation: All persons handling or working on the FML should conform to dress requirements.
- Alternatives: The liner contractor could assume responsibility for a daily check of his employees. The CQA inspector would then receive an acceptance report from the contractor and make spot observations throughout the day for noncompliance.

ANCHORS/ATTACHMENTS

In nearly all cases where the supporting surface for an FML is soil, the edge of the FML will be anchored in an earth trench. In those cases where the liner edge must be attached to a material such as concrete, battens and bolts are generally used (see Figure 7-1 for an example of a batten). Reglets are also used (see Figure 7-2). At piping, a pipe boot made out of the FML and a clamp may be used (see Figure 7-3), or the FML used as a gasket between two pipe flanges.

Earth Anchor Trenches

The minimum design requirements for an earth anchor trench are determined by the following criteria:

- There must be sufficient trench depth and width to resist pulling of the FML edge out of the trench.
- There must be sufficient distance from the edge of the trench to the top of the slope so that the top of the slope will not slough to the downward pull of the FML after a surface loading is applied.

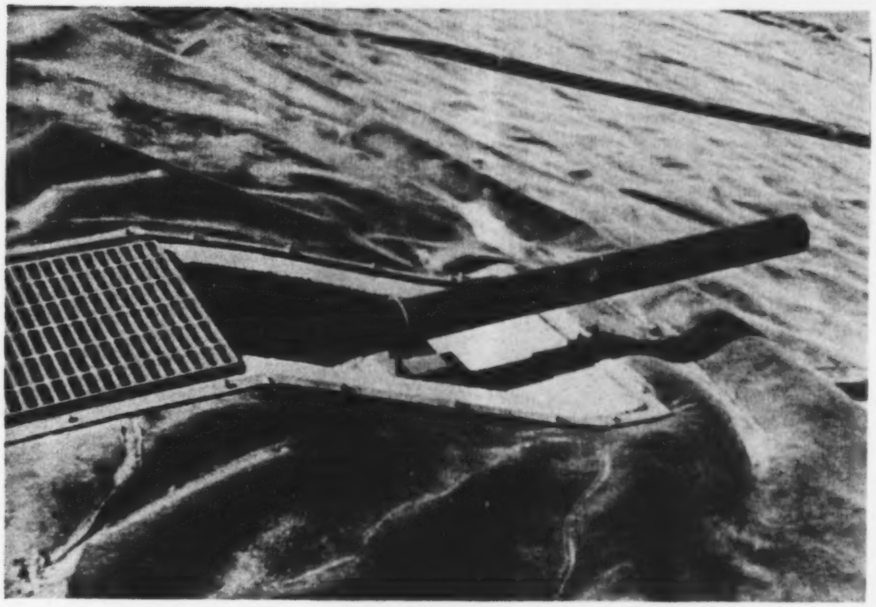


Figure 7-1. FML battened to concrete structure

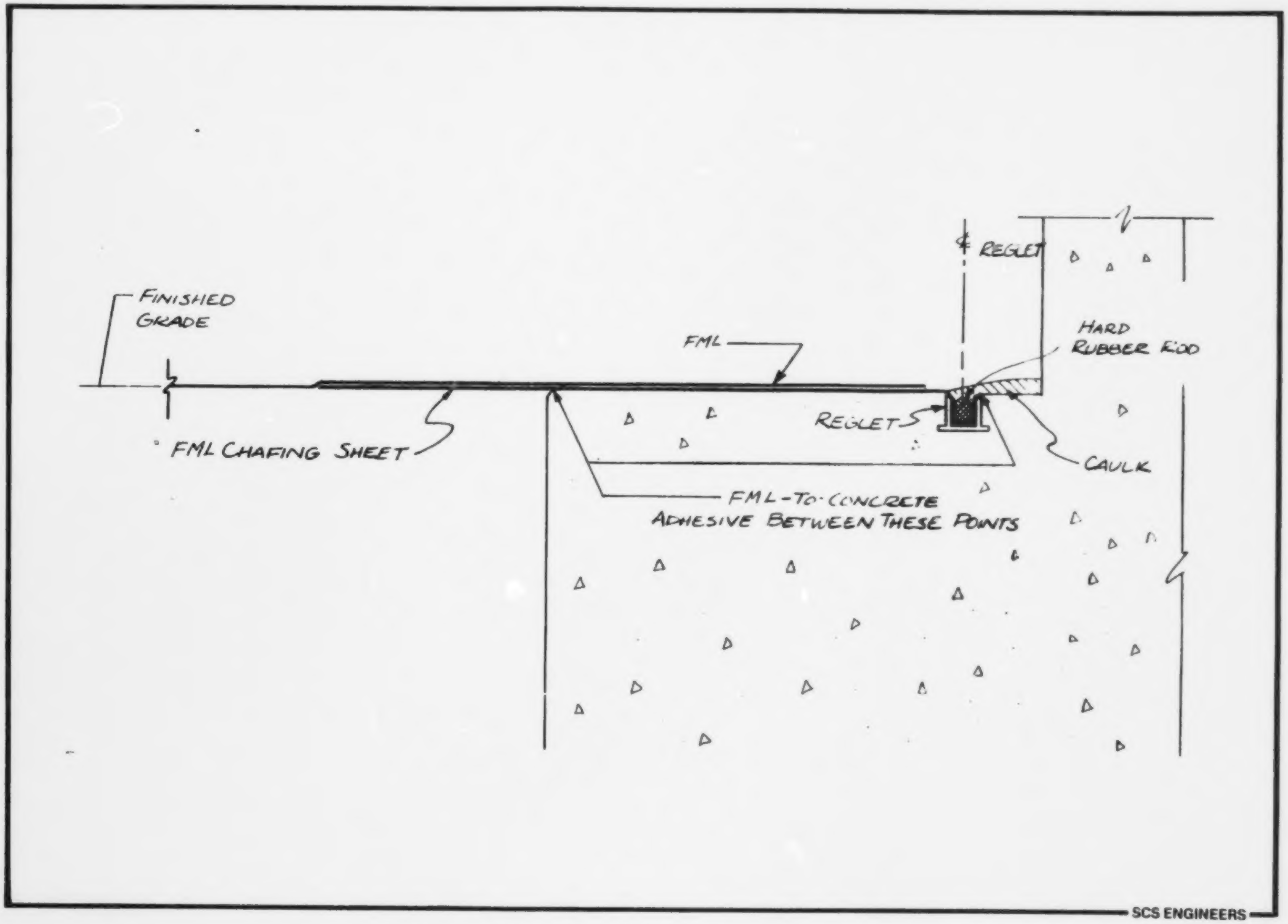

FINISHED GRADE
FML
℄ REGLET
HARD RUBBER ROD
REGLET
CAULK
FML CHAFING SHEET
FML-TO-CONCRETE ADHESIVE BETWEEN THESE POINTS
SCS ENGINEERS

Figure 7-2. Detail of reglet connection

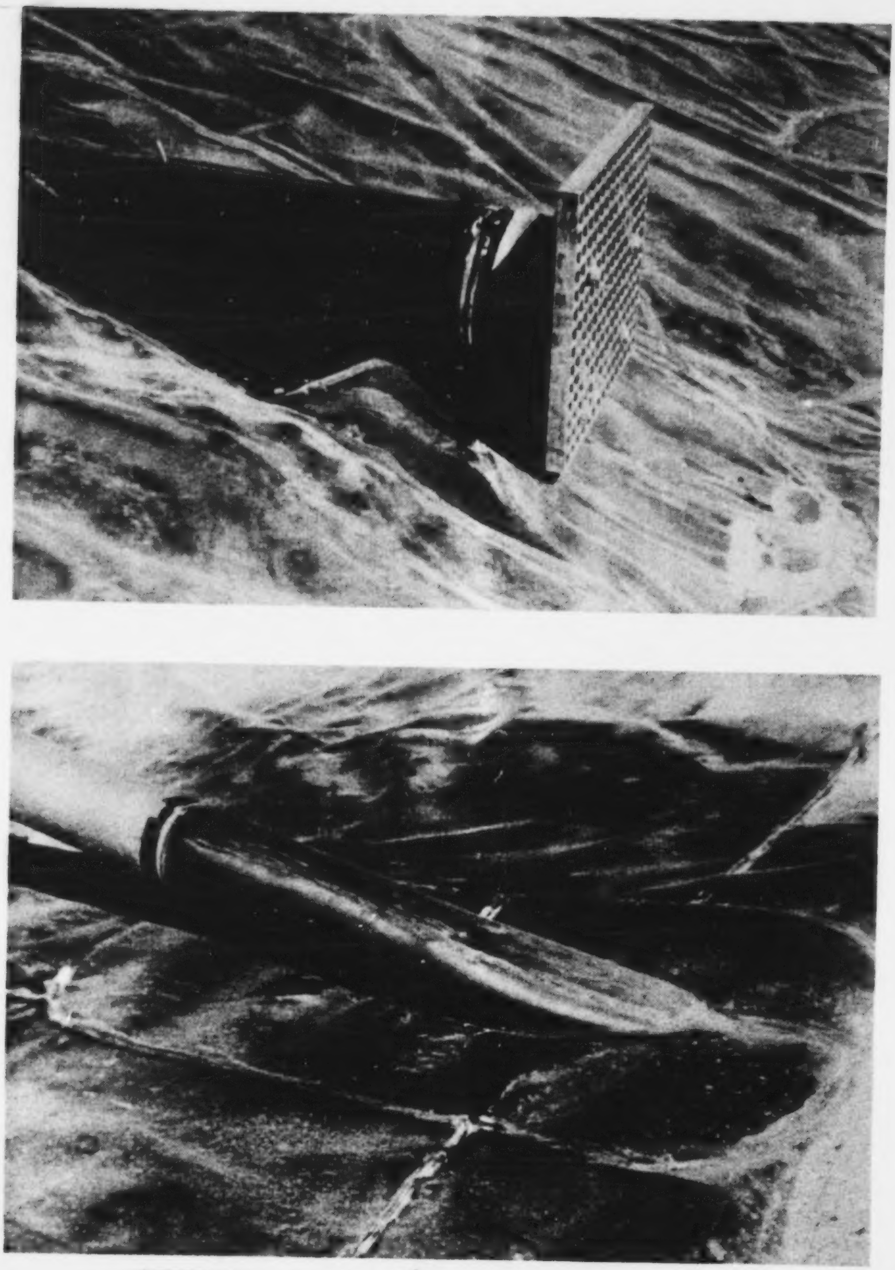


Figure 7-3. FML boot clamped to pipe

For PVC, CPE, and CSPE, the minimum acceptable depth and width for a trench are 30.5 centimeters (1 foot) and 30.5 centimeters (1 foot), respectively. For these FMLs, the minimum acceptable distance of the trench from the top of slope is 30.5 centimeters (1 foot). A typical anchor trench for these FMLs is shown in Figure 7-4. For HDPE, the minimum depth and width are 61 centimeters (2 feet) and 30.5 centimeters (1 foot), respectively, and the trench should be 60 centimeters (2 feet) to 1 meter (3 feet) from the top of the slope. An HDPE anchor trench is shown in Figure 7-5.

Anchor trenches should be backfilled with a clean, well-graded soil (usually material excavated from the trench). The soil should be carefully compacted in the trench. Unless specified, the FML does not need to be fully seamed in the trench.

Inspection Procedures--

- Method: Visually observe the perimeter anchor trench before the FML is placed and the trench backfilled to ensure the following:
  - Trench depth and width (and distance from slope, if applicable) meet specifications.
  - The leading edge of the trench is smooth and free of sharp or jagged edges.
  - Temporary anchoring methods (sand bags) do not damage the FML.
  - FML is properly installed in the trench.
  - Earth fill for the anchor trench is free of sharp rocks.
  - Final backfilling and compaction operations do not damage the FML.
- Location: The entire perimeter trench should be observed.
- Documentation: The inspector should keep accurate records in the daily diary, noting where sections of trench are completed, trench dimensions, and personnel engaged in anchoring procedures.
- Interpretation: FML anchoring in earth trenches must be performed in accordance with design specifications to ensure lining security.

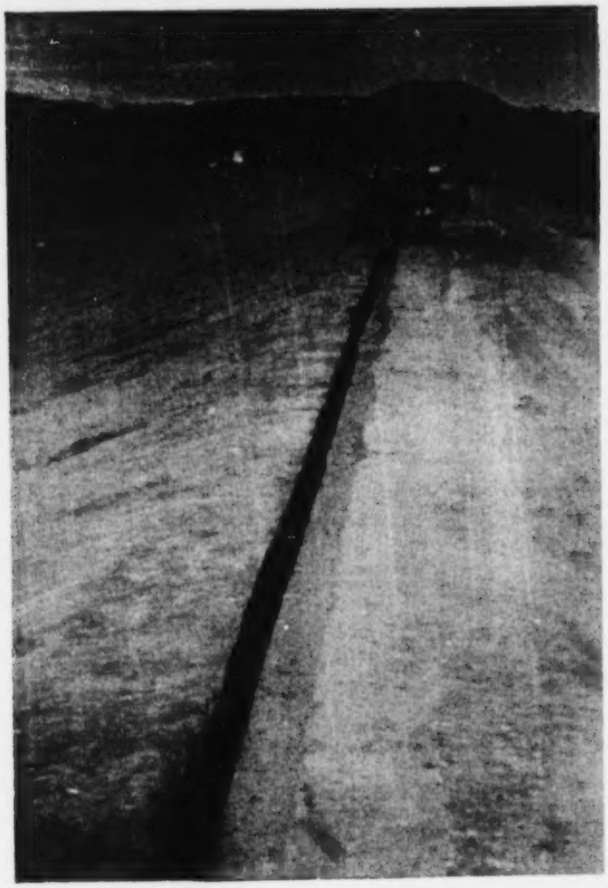


Figure 7-4. Anchor trench for CSPE FML

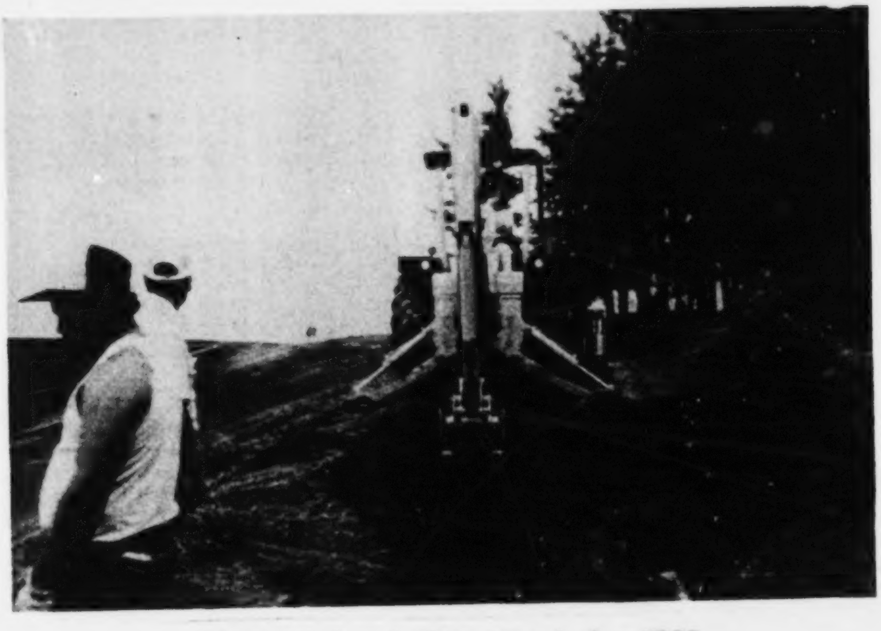


Figure 7-5. Anchor trench for HDPE

Concrete

It is not unusual for an FML to be penetrated by the concrete structures and pipes to which the FML is attached.

FMLs can be attached to concrete with battens and bolts or reglets. An important consideration is whether or not the attachment will ever be submerged. If an attachment is to be submerged, it must be sealed to avoid leakage. An attachment that will not be submerged does not need to be sealed.

Prior to attachment of the FML, an important consideration is the concrete itself. The inspector should check the following items:

- Determine how the concrete was cured.
- Ensure that no wax or slick curing compound was used.
- Make sure that surfaces are smooth and free of voids, jagged edges, and sharp protrusions.

Battens and Bolts--

A batten is a long thin metal bar. It is used in conjunction with anchor bolts to clamp the FML at the place of attachment to a concrete structure or pipe.

Important features include:

- Spacing of anchor bolts - This is dependent on the type of FML being used. Generally, stiffer FMLs such as HDPE will require closer spacing of bolts to provide adequate support, whereas more flexible materials such as PVC and CSPE tolerate wider spacing. Bolt spacing should follow the details shown on the design plans.
- Bolt, nut, and washer material - Generally, stainless steel is acceptable; however, metal alloy combinations are sometimes preferred.
- Batten material - Stainless steel is normally used, but more metal alloys can be used.
- Padding - For HDPE, one or more layers of padding are recommended to protect the FML when the nut is tightened down on the batten. Closed cell neoprene is most commonly used.
- Adhesives - Various layers of adhesive or butyl tape are used to ensure a union between the liner and batten (and padding). A typical batten and bolt combination is shown in Figure 7-1.

Inspection procedures--

- Method: Visually observe the attachment surface and batten and bolt materials before the lining is attached to ensure the following:
  - Surface to which the FML is to be attached is smooth and free of ridges, sharp edges or bumps, and voids.
  - Materials are compatible. For example, never attach an aluminum batten strip with steel nuts and bolts without separating with Teflon washer nipples.
  - Materials (batten bars, padding, bolts, etc.) are consistent with the design. This includes certification from the manufacturer or supplier that the material meets or exceeds specifications.
  - Adhesives, cements, tapes, and caulks are of a type recommended or approved by the FML manufacturer.
  - Materials are fresh, free of defects, and of the proper dimensions.
- Location: The entire attachment should be observed.
- Documentation: The inspector should maintain accurate records in the daily diary, noting when sections of the attachment are completed, the types and dimensions of materials used, any delays or problems encountered, and personnel engaged in the attachment process.
- Interpretation: An attachment can fail due to improper installation, tearing of the FML at the attachment, or corrosion of the batten material. Installation must be performed in accordance with design specifications and manufacturer recommendations. The inspector should question the use of any metal other than stainless steel or any material that is not strictly in accordance with specifications.

Reglets--

A reglet is a small, long plastic U-shaped piece into which the edge of the FML is inserted; a long hard rubber rod is placed into the U to secure the FML.

The plastic U is set into the concrete form before the concrete is poured or before it cures. The FML edge is inserted inside the U; then the rubber rod is inserted. Finally, a thick bead of caulk is run along the top of the reglet, FML, and rubber rod as a final seal. A typical reglet is shown in Figure 7-2.

Inspection procedures--

- Method: Visually observe the attachment surface and reglet materials before the lining is attached to ensure the following:

  - The reglet is properly set in the concrete and flush with the concrete surface. No voids exist in the concrete alongside the reglet.

  - The reglet is of the material and size specified.

  - The surface to which the FML is to be attached is smooth and free of ridges, sharp edges, bumps, and voids.

  - Adhesive, cements, tapes, and caulks are of a type recommended or approved by the FML manufacturer.

  - Materials are fresh, free of defects, and of the proper dimensions. At completion of the work, visually observe that the FML edge is properly inserted into the reglet; the rubber rod is properly inserted; and the caulk bead is of the proper material and is properly placed.

- Location: The entire attachment should be observed.

- Documentation: The inspector should keep accurate records in the daily diary, noting when sections of the attachment are completed, the types and dimensions of materials used, any delays or problems encountered, and personnel engaged in attachment procedures.

- Interpretation: An attachment can fail due to improper installation, tensing of the FML at the attachment, or failure of the rubber rod to hold. Installation must be done in accordance with design specifications and manufacturer recommendations. The inspector should question the use of any material not strictly in accordance with specifications.

Piping

At many facilities, it will be necessary to attach the FML to one or more pipes that protrude through the FML. The two most common methods of attachment are a pipe boot and batten and bolts. The boot is generally of the same material as the FML; it is attached by adhesive, heat, or fusion welding to the FML and pipe using SS metal clamps on the pipe. If both the pipe and the FML are HDPE, the boot is welded to both and no clamp is used.

If a pipe boot cannot be used, the FML is generally attached to a concrete shelf surrounding the pipe (flush with the supporting surface) using battens and bolts, or the method previously discussed.

Another method involves using the FML as a gasket between two pipe flanges. The bottom flange is flush with the concrete shelf surrounding the pipe. The FML is placed thereon; holes are punched in the FML to fit the flange bolts, and the upper pipe ring flanges are secured to the FML and lower flange using bolts and nuts. This type of attachment is similar to the batten and bolts previously discussed.

Inspection Procedures--

- Method: Visually observe the attachment surfaces of the pipe and/or surrounding concrete shelf to ensure that:
  - The surfaces are free of burrs, rough areas, projections, and voids.
  - If a pipe flange is part of the attachment, it is flush with the surrounding concrete surface.
  - Adhesives, cements, tapes, caulks, and other materials are of a type recommended or approved by the FML manufacturer. At completion of the work, visually observe that the attachment is made according to the plans and specifications, and that all potential visual leaks paths have been adequately caulked.
- Location: Each attachment should be observed.
- Documentation: The inspector should keep accurate records in the daily diary, noting the locations and types of mixing attachment, materials used, any delays or problems encountered, and personnel engaged in the attachment installation.
- Interpretation: An attachment at a pipe may fail for the same reasons as attachments at other locations. Due to the greater potential for leaks to occur at attachments, it is important that extra care and effort go into their construction. The quality of the material used and the care taken in the installation are of utmost importance.

CHAPTER 8

TESTING

INTRODUCTION

Several methods are used to test factory and field seams and patches. Test methods can be destructive and/or nondestructive.

Nondestructive tests are performed in the field on in-place FML. Nondestructive tests retain the integrity of the FML seam or sheet being tested.

Destructive tests are performed in either the field or laboratory. The intent is to determine the strength characteristics of a seam sample by stressing the sample until either the seam or the FML sheeting fails.

Table 8-1 lists the most commonly used field and laboratory test methods, and indicates whether the tests are destructive or nondestructive. In addition, the most common test methods for each FML type are noted.

Testing is performed on in-place FML seams sheets and patches and on samples of FML seams. Seam samples can be either destructive or nondestructive, depending on the method by which they were obtained.

Nondestructive Samples

Field-fabricated start-up seams are a representative seam fabricated from the same material and using the same seaming methods as those recommended by the FML sheet manufacturer. The startup seam shall be no less than 3 meters (10 feet) in length, and shall be provided at the start of each day's or shift's seaming. Random samples for shear and peel testing are cut from the startup seam. The seam must be allowed to cure or age properly before testing in accordance with manufacturer's directions.

Random field-fabricated seam samples are similar to field-fabricated startup seam samples except that they can be taken randomly at the discretion of the inspector/CQA officer using the seaming techniques employed by the seaming crew at the time the random sample is requested (i.e., the sample sheets should be seamed in a manner similar to the field sheets, and no additional

TABLE 8-1. METHODS COMMONLY USED TO TEST FML SEAM AND SHEET INTEGRITY

	FML Type					
Test Method	PVC	CSPE	CPE	HDPE	Destructive Test	Nondestructive Test
Field						
Probe*	X	X	X	X		X
Air Lance*	X	X	X	X		X
Vacuum Box*‡				X		X
Ultrasonic Pulse Echo*‡				X		X
Ultrasonic Impedance Plane	X	X	X	X		X
Spark*‡	X	X	X	X		X
Pressurized Dual Seam				X		X
Electrical Resistivity#	X	X	X	X		X
Hydrostatic#	X	X	X	X		X
Seam Strength Peel	X	X	X	X	X	
Seam Strength Shear					X	
Laboratory						
Bonded Seam Strength Shear	X	X	X	X	X	
Bonded Seam Strength Peel	X	X	X	X	X	

* See Figures 8-2, 8-3, 8-4, 8-5, and 8-6, respectively, for an illustration of the test method.

‡ May be used on all FML of 30 mil or greater sheet thickness.

# Tests both seam and sheet integrity. All others test for seam integrity only.

or alternative cleaning effort should be made by the seaming crew). The seam must be allowed to cure or age properly before testing in accordance with manufacturer directions.

Destructive Samples

A destructive sample consists of a 60-centimeter (2-foot) long section of fabricated seam cut from the installed lining (see Figure 8-1). The cutout section should be wide enough to accommodate peel and shear testing. Random specimens for peel and shear testing are cut from the sample. The frequency of cutouts can be determined by the size of the FML installation, and may require only one or two cutouts. The resulting hole is patched with a piece of sheet material and seamed in accordance with the manufacturer's instructions. Before testing, the cutout seam should be allowed to cure or age properly in accordance with manufacturer directions. A minimum of one sample per seaming crew per day should be tested.

Nondestructive sampling is recommended over destructive sampling except when the following conditions exist:

- There are an insufficient number of inspectors to observe each seaming crew full time.
- Results of testing a nondestructive sample indicate poor seam quality.

If one or more of the above conditions prevail, the inspector should recommend to the CQA officer to implement an agreed-upon destructive sampling program to supplement nondestructive sampling.

FIELD TESTS

Probe Test (Mechanical Point Stressing)

- Purpose: This test is designed to detect leak paths and unbonded edges of seams.
- Method: A dull-pointed probe (e.g., a blunted ice pick) is run along the edge of a seam to detect seam defects (see Figure 8-2). All defects detected are marked on the sheet for repair.
- Frequency: Ongoing to assure that each factory and field seam (including patching) is probe-tested.
- Location: All seams and patches should be tested.

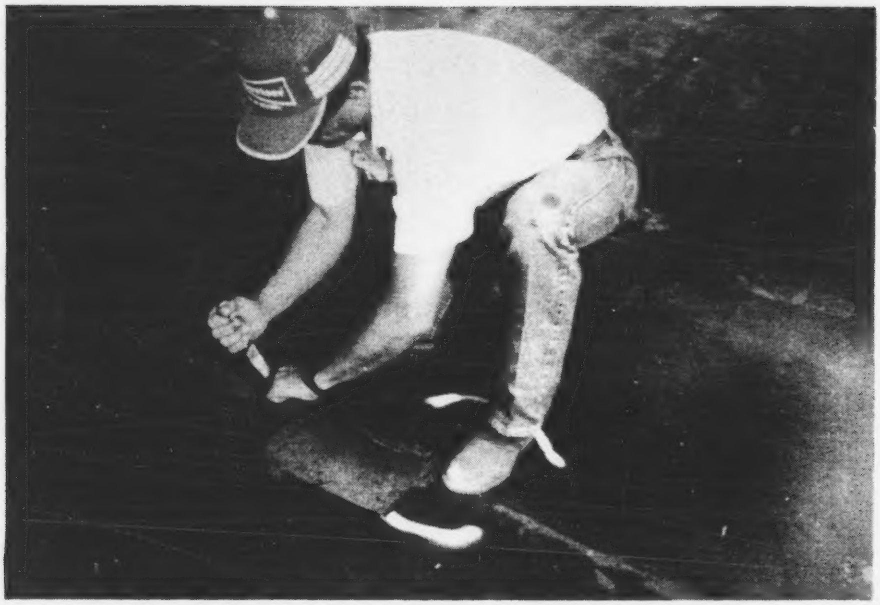


Figure 8-1. A field cut-out seam being prepared

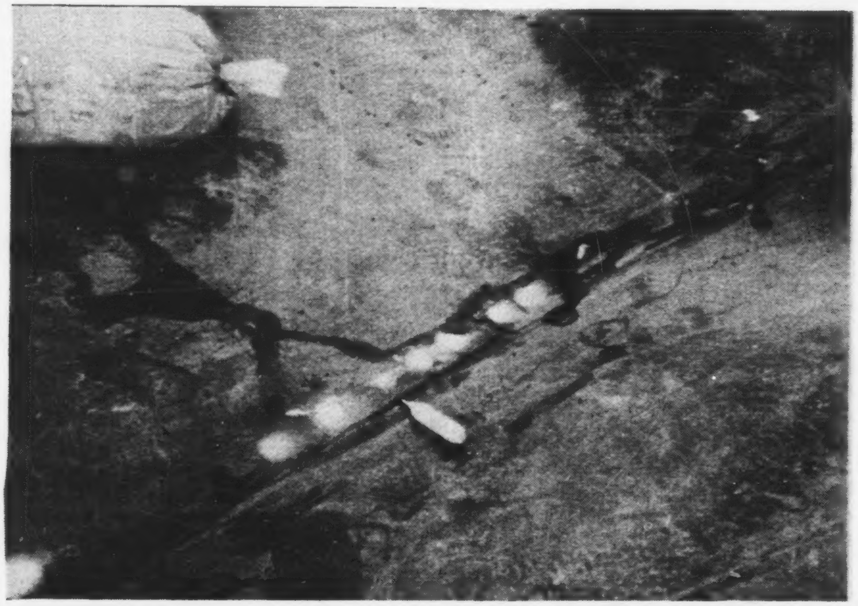


Figure 8-2. Probe testing of HDPE

- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Names of personnel performing the test should also be recorded.

- Interpretation: Defective seams should be repaired and retested.

- Limitations: The probe test will normally only detect unbonded areas that are open at the top edge of the seam. However, if a suspicious area is detected (even though the edge of the seam is bonded), the probe may be used to carefully poke through the edge to probe the suspicious area.

- Alternatives: None. The probe test is normally a fundamental part of a CQA program. Other field testing is usually done in addition to the probe test.

Air Lance

- Purpose: This test is designed to detect leak paths and unbonded edges of seams.

- Method: A stream of air is directed at the edge of a seam through a small-diameter nozzle (e.g., 0.5-centimeter [3/16-inch]) at a relatively high pressure (minimum 3.5 kilograms per square centimeter [50 pounds per square inch] held not more than 5 centimeters [2 inches] from the seam edge) (see Figure 8-3). The stream of air will tend to inflate leak paths, and will also lift unbonded edges. Unbonded edges will tend to vibrate when subjected to the air stream, resulting in an audible signal. All defects are marked on the FML for repair.

- Frequency: Ongoing to assure that each factory and field seam (including patching) is air lance-tested.

- Location: All seams and patches should be tested.

- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Names of personnel performing the test should also be recorded.

- Interpretation: Areas of a seam that become inflated indicate unbonded areas. Vibrating or uplifting of edges of the seam indicate unsealed edges. Defective seams should be repaired and retested.

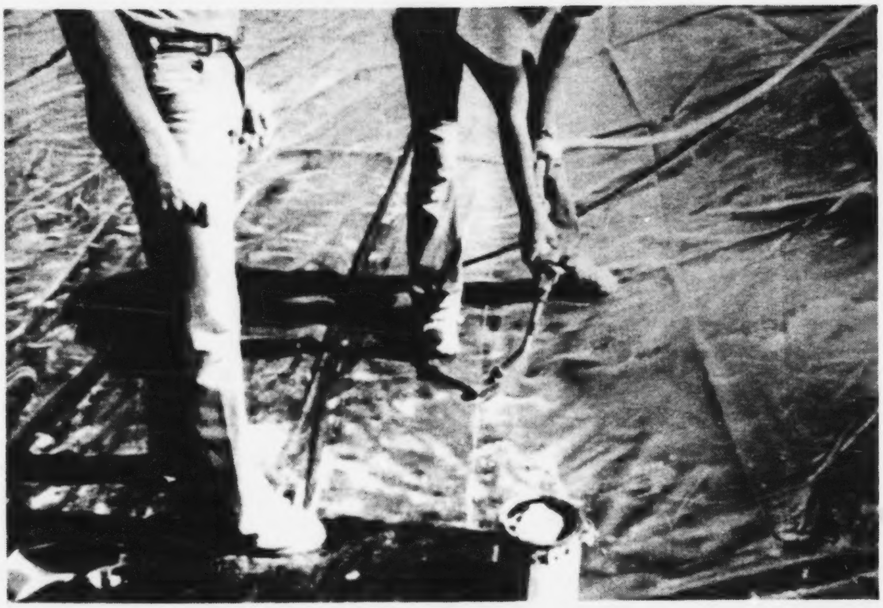


Figure 8-3. Air lance testing of FML

- Limitations: The air lance will only detect unbonded areas that are open at the top edge of the seam. Unbonded areas that are closed at the edge of a seam will not be detected by this method. Also, this method is less effective for testing the thicker and less flexible liners such as HDPE.

- Alternatives: Vacuum box.

Vacuum Box

- Purpose: This test is designed to detect leak paths in seams, or pinholes in sheets.

- Method: The seam areas of the liner to be tested are cleaned of all dirt and other foreign matter; a soap solution is then applied. A vacuum box equipped with a vacuum gage, a clear glass panel in the top, and a soft rubber gasket on the periphery of the open bottom (a vacuum box similar to the Series A 100 straight seam tester as supplied by the American Parts and Service Company) is sequentially placed over sections of the soaped seam area and the gasket sealed to the FML. A vacuum of 1,380 to 2,760 kilograms per square meter (4 to 8 inches of mercury) is then applied to the vacuum box using a gasoline- or electric-driven power vacuum pump apparatus. The applied vacuum will cause bubbles to form in the soap solution over unbonded areas. All defects detected are marked on the sheet for repair. Figure 8-4 shows a vacuum box being used to test a HDPE field seam.

- Frequency: Ongoing. At a minimum, each factory and field seam and each patch are vacuum-tested.

- Location: All seams and patches should be tested.

- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Names of personnel performing the test should also be recorded.

- Interpretation: Bubbles will form along the edge of a seam or atop a pinhole if a leak path is present. The vacuum test will only detect actual leak paths. Not all unbonded areas will necessarily be detected. Defects should be repaired and retested.

- Limitations: The vacuum test is difficult to use on steep slopes, and the liner must be flat in order to obtain a good seal between the box and the liner. The vacuum test has questionable value to test thin FMLs (less than 30 mils). The thinner, more flexible liners

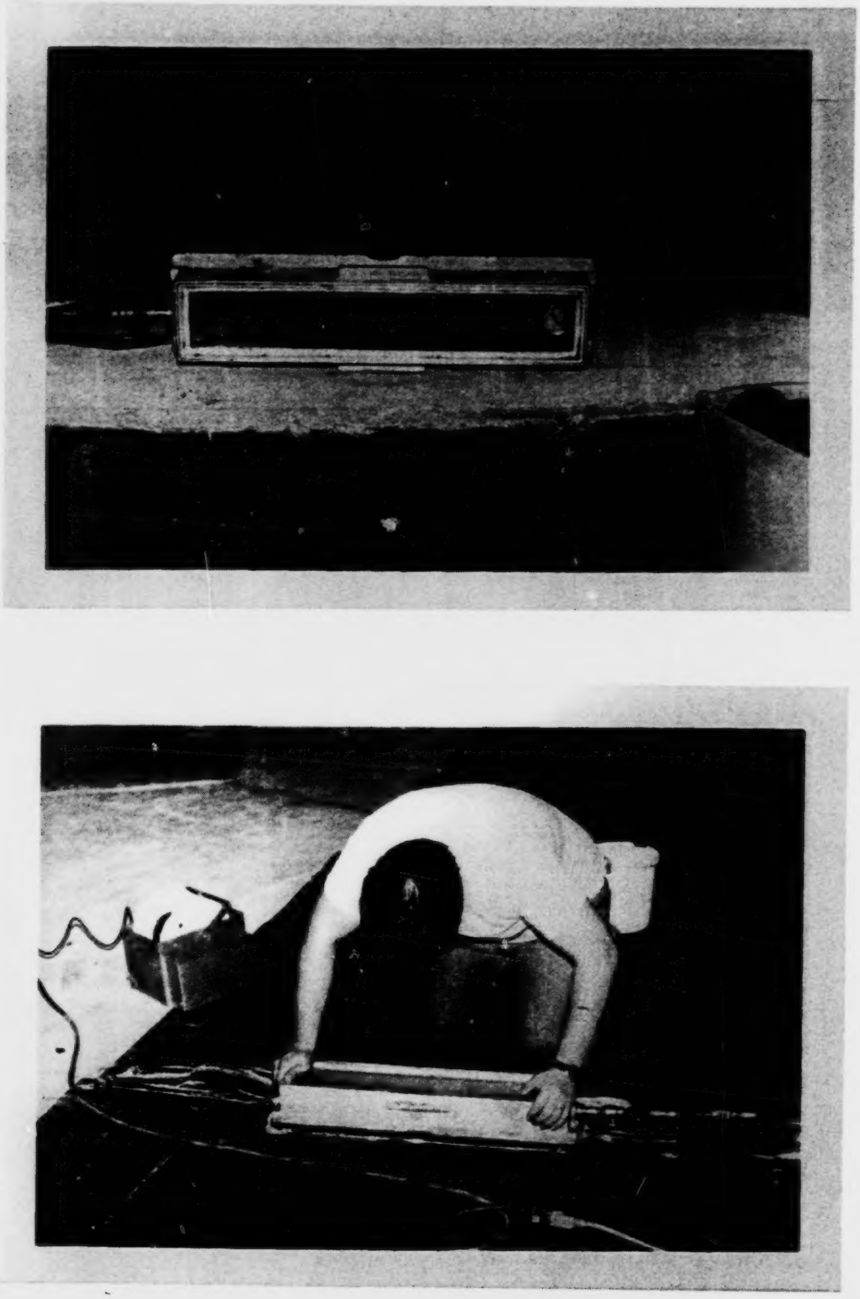


Figure 8-4. Vacuum box testing of HDPE

have a tendency to pin themselves together when vacuum-tested, thereby effecting a seal. Vacuum testing is a widely used method for testing HDPE.

- Alternatives: Air Lance.

Ultrasonic (High-Frequency) Pulse Echo

- Purpose: This test is designed to detect major voids or defective areas in the seam.

- Method: Nonreinforced field seams are tested by passing a high-frequency sound wave through the seam overlap to detect discontinuities in the bonded seam. A commercially available frequency generator capable of producing frequencies in the range of 5 to 15 MHz should be used. The contact send/receive transducer head should be the width of the bonded seam width, and should be capable of being moved at the rate of 1.5 to 2.1 meters per minute (5 to 7 feet per minute) along the surface length of the seam area. The transducer head should be designed to give continuous surface-to-surface thickness measurements once calibrated. Good contact of the test head with the FML surface is assured by providing a continuous contact medium (water) at the interface between the test head and the FML. The ultrasonic signal should be viewable on a monitor and capable of triggering an audible alarm when a discontinuity is detected. Discontinuities should be marked for repair after detection. Figure 8-5 shows an FML seam being inspected using this technique.

- Frequency: Ongoing. All seams should be tested.

- Location: All seams are to be tested using this method.

- Documentation: Field notes should be maintained on a print of the sheet layout to monitor the seams that have been inspected and to record the location of defects. Calibration of the testing equipment should also be recorded, as well as names of personnel performing the test.

- Interpretation: Major voids or defective areas of a seam will be indicated by echoes with an earlier return time than those from well bonded areas. Defective areas should be repaired and retested.

- Limitations: The ultrasonic pulse echo test requires the most sophisticated equipment of all the field tests. It also requires experienced personnel to perform the testing. Ultrasonic testing is primarily used to test HDPE seams. However, it is capable of testing seams in other

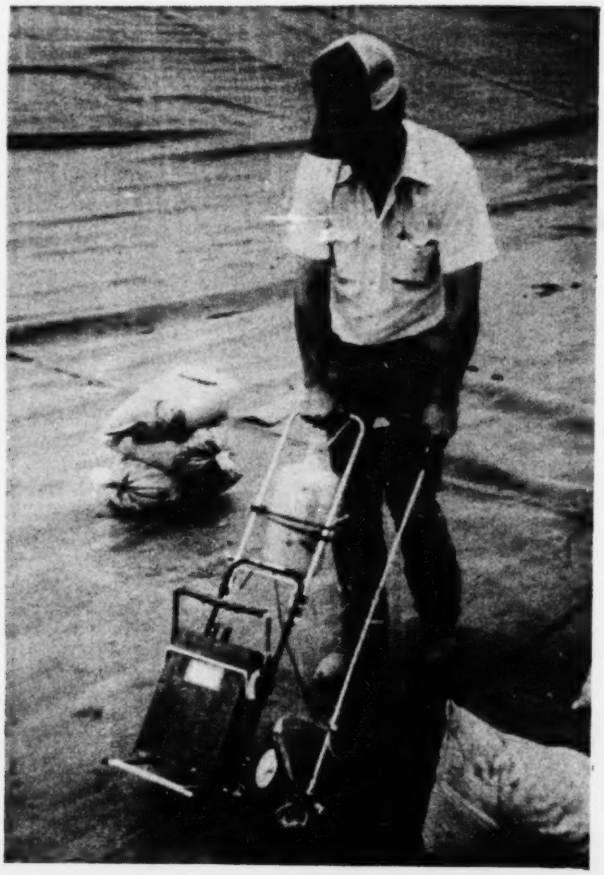


Figure 8-5. Seam testing using pulse echo technique

nonreinforced FML materials, such as PVC, with thicknesses greater than 30 mils.

- Alternatives: Vacuum box.

Ultrasonic Impedance Plane

- Purpose: This test is designed to detect leak paths and unbonded factory and field seams.
- Method: The Ultrasonic Impedance Plane (UIP) technique works on the principle of characteristic acoustic impedance. A well bonded seam possesses a different acoustic impedance after calibration than an unbonded seam. In order to characterize a well bonded seam, a continuous wave resonant frequency of 160 to 185 kHz is transmitted by means of a surface transducer, forming a characteristic dot pattern on a cathode ray tube (CRT) monitor. Location of this specific dot pattern on the screen indicates a good bond; any variation of this pattern indicates an unbond or an uncoupled transducer. The operator visually inspects and marks all unbonded areas for repair. This method can be applied to supported as well as unsupported FMLs as the scrim reinforcement does not appear to affect the low-frequency transmission.
- Frequency: Ongoing to ensure that all seams and patches are tested.
- Location: All seams and patches should be tested.
- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Documentation should include names of personnel performing the test and UIP equipment make and model number.
- Interpretation: Defective seams should be repaired and retested.
- Limitations: A surface transducer must be used that is wide enough to be able to scan the full width of a given seam along the entire bond length. Improvements in method of application are needed to increase both the speed and accuracy of testing. The present speed of testing is only 1 to 2 meters per minute (3 to 6 feet per minute).
- Alternatives: All other test methods except the air lance for HDPE, the vacuum box for thin (< 30 mil) FML, and dual seam pressurization.

Electrical Spark Test

- Purpose: This test is used to detect voids, pinholes, or unbonded areas primarily in HDPE welds. It can also be used to test in solvent bonds.
- Method: All seams are provided with copper wires properly embedded in the seam and grounded. A high-voltage (15 to 30 kv) electrical current is then applied to the seam area using a high-voltage detector (similar to Tinker and Razor Holiday Detector Model AP-W), and any leakage to ground is detected by sparking. Figure 8-6 shows a seam equipped with a spark test wire and the testing apparatus.
- Frequency: Ongoing to assure that all field seams and patches are spark-tested.
- Location: All field seams and patches are tested.
- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Names of personnel performing the test should also be recorded.
- Interpretation: Defective seams should be repaired and retested.
- Limitations: Electrical spark testing is best suited for thicker FML (> 30 mil). Insertion of the copper wire into solvent-bonded/adhesive-bonded seams slows the seaming rate.
- Alternatives: Air lance (PVC, CSPE, and CPE), vacuum box, ultrasonic pulse echo (HDPE).

Pressurized Dual Seam

- Purpose: This test is designed to detect leak paths and unbonded edges of double wedge thermally welded seams where an air chamber exists between the seams.
- Method: After the dual wedge seam has been fabricated for a given length, both ends are sealed. A needle with attached pressure gauge and air valve is inserted into the air space between the thermally welded areas, and pressure (usually 207 kPa [30 psig]), is applied to the air channel. The gauge is monitored for a drop in air pressure over time as an indicator of a seam unbond or leak.
- Frequency: Ongoing to assure that all seams are tested.

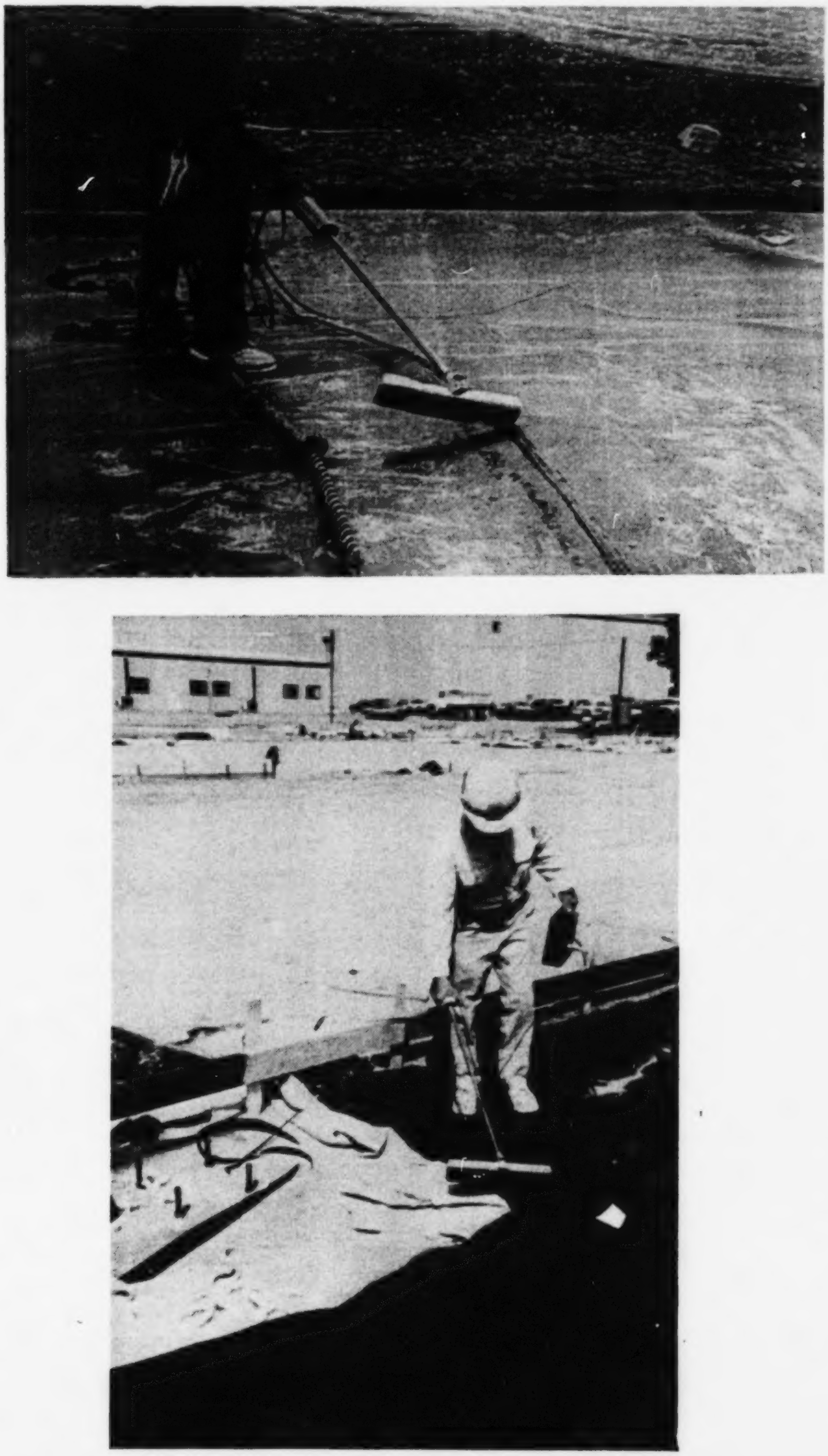


Figure 8-6. Spark testing of HDPE

- Location: All seams are tested.

- Documentation: Field notes should be maintained on a print of the sheet layout to record detected defects and to monitor the seams that have been inspected. Names of personnel performing the test should also be recorded.

- Interpretation: Defective seams should be repaired and retested.

- Limitations: If a leak is detected, the entire length of the seam being tested must be rechecked using a vacuum box, or the length must be cap-stripped.

- Alternatives: Vacuum box.

Electrical Resistivity

- Purpose: To detect holes, seam unbonds, and improper penetration seals in FML installation.

- Method: The pre-service containment is filled with 20 to 75 centimeters (8 to 30 inches) of water. A lightweight man-portable electrical probe is then inserted into the water to detect leak locations where there is no resistance to electrical current offered by the FML. To make a complete survey, a series of horizontal transverse lines are established and scanned with the probe for coverage on each side of the transverse line. When leaks are detected, they are accurately located to within 1.25 centimeters (0.5 inch) or less, and are immediately marked with lead markers and floats. Surveys can be conducted in up to 3.5 meters (12 feet) of water using a small boat.

- Frequency: This test is performed after the entire FML installation is completed and prior to receiving wastes.

- Location: The entire FML installation is tested.

- Documentation: Field notes should be maintained on FML layout plans to record any leaks detected. Names of personnel performing tests should be recorded.

- Interpretation: Defective FML sheets seams and penetration seals should be repaired and retested.

- Limitations: The maximum distance at which a leak can be detected depends on several variables, e.g., hole size, conductivity of the impounded liquid. Most pinholes are detected at distances of at least 46 centimeters (18 inches). Many large leaks can be detected at a distance of at least 125 centimeters (50 feet).

Metal pipes, bolts, studs, and even concrete pipe and valve supports that penetrate the liner make excellent electrical conducting paths that interfere with measurements or cause nearby leaks to be overlooked by the detector. Such interference impacts can often be minimized or eliminated by special actions and temporary arrangements ranging from plugging and draining penetrating pipes to using small cofferdams to isolate large structures which are normally in contact with the liquid.

If the FML has an air-filled void under it which did not fill with liquid from the leak, no electric current path would exist, and detection would not be possible. The liquid must complete an electric current path to the underlying earth for detection to occur.

- Alternatives: Hydrostatic test.

Hydrostatic Test

- Purpose: This test is designed to detect for any leaks in the FML including pinholes, tears, seam unbonds, and faulty attachments to penetrations.
- Method: The containment is filled with water to the maximum depth that will be exposed to hazardous waste. Any reduction in water level over the specified period of time is then measured using a float (hook) gauge for a single FML, and a monitoring well for the upper FML of a double FML installation.
- Frequency: This test is performed after the entire FML installation is completed and prior to receiving wastes.
- Location: The entire FML installation is tested.
- Documentation: Field notes should be maintained on the FML layout plans to record any leaks detected. Names of personnel locating leaks should be recorded.
- Interpretation: Defective FML sheets, seams, and penetration seals should be repaired and retested.
- Limitations: Depends on the availability of water and the size of the FML installation.
- Alternatives: Electrical resistivity.

Seam Strength Peel Test Field

- Purpose: This is a field test designed to detect problems in field seaming materials and procedures.

- Method: Samples of seams are made in the field as the installation progresses, using the same materials and techniques that are used for the liner. The samples for the peel test are seamed using pieces of liner material. The two pieces are seamed together along one side only in a manner that will provide "ears" on which to pull to put the seam in peel. For PVC, CSPE, and CPE, the seam must be allowed to cure for a minimum of 12 hours prior to being cut for sampling; HDPE can be cut for sampling after only a few minutes. These samples are then pulled apart in peel. The reinforced FMLs (e.g., CPE, CSPE) can be easily tested by hand. If well bonded, reinforced materials should fail due to delamination of one of the sheets. However, well bonded unreinforced materials such as HDPE or PVC, when tested in peel, should fail due to tearing of one or both of the sheets. To test such materials, other equipment such as mechanically operated vice grips might be required to apply sufficient force.

- Frequency: One peel seam sample per day is the minimum requirement. In larger installations, one sample per 150 meters (500 feet) of field seam is normally required.

- Location: Test samples are made in the field alongside the actual seams.

- Documentation: The samples should be numbered, dated, identified as to the personnel making the seam, and keyed to the location of field seam work in progress at the time the sample is made; appropriate notes should be maintained on a print of the sheet layout. Weather conditions at the time the samples are made should also be recorded. Results of test samples should be recorded for each sample.

- Interpretation: The results of the peel test will identify any problems with the seaming materials or techniques. Well bonded reinforced materials will fail due to delamination of one of the sheets. Well bonded nonreinforced materials will fail by tearing of one or both of the sheets.

Seam Strength Shear Test Field (HDPE Only)

- Purpose: This field test is designed to detect problems in field seaming materials and procedures for HDPE only.

- Method: Samples of seams are made in the field as the installation progresses using the same materials and techniques that are used for the liner. Samples for testing can be cut from seam samples only a few minutes after seaming. These samples are then pulled apart in shear using a mechanically operated vice grip device.

- Frequency: One shear seam sample per day is the minimum requirement. In larger installations, one sample per 150 meters (500 feet) of field seam is normally required.

- Location: Test samples are made in the field alongside seams being made in the field.

- Documentation: The samples should be numbered, dated, identified as to the personnel making the seam, and keyed to the location of field seam work in progress at the time the sample is made; appropriate notes should be maintained on a print of the sheet layout. Weather conditions at the time the samples are made should also be recorded. Results of test samples should be recorded for each sample.

- Interpretation: The results of the shear test will identify any problems with the seaming materials or techniques. Well bonded HDPE will fail due to breaking of the material outside the seam.

LABORATORY TESTS

Bonded Seam Strength in Shear of Unreinforced FMLs (ASTM D 3083 - Specification for Flexible Polyvinyl Chloride Plastic Sheeting for Pond, Canal, and Reservoir Lining, As Modified by ASTM D 882 or ASTM D 638)

- Purpose: This laboratory test is designed to determine the breaking factor (kilograms per centimeter, or pounds per inch of width) of seams in shear for unreinforced FMLs.

- Method: ASTM D 3083, Paragraph 9.3, modified to allow either Method A or Method B of ASTM D 882 or ASTM D 638 for HDPE:

  - Method A - Static Weighing: This method employs a constant rate of separation of the grips holding the ends of the test specimen.

  - Method B - Pendulum Weighing: This method employs a constant rate of motion of one grip and a variable rate of motion of a second grip. The variable rate grip is attached to a pendulum weighing head. Its movement is dependent on the load deformation behavior of the material tested.

- ASTM D 638: This method is for HDPE and employs a constant rate of separation of the grips holding the ends of the test specimen. The grip separation rate is different than in ASTM D 882 in order to accommodate the different properties of the HDPE material.

Specimens 2-1/2 centimeters (1 inch) wide are used with a grip separation of 10 centimeters (4 inches) plus the width of the seam. The seam is centered between the clamps. Five specimens are tested for each sample. Seams should cure for a minimum of 12 days prior to testing, except in the case of HDPE which does not need to cure. Each specimen is strained at a rate of 50 centimeters (20 inches) per minute, except for HDPE which is strained at a rate of 5 centimeters (2 inches) per minute. The maximum load for each specimen is recorded. The breaking factor is calculated by dividing the maximum load by the original minimum width of the specimen.

- Frequency: The specimen should be taken from samples of both factory (if applicable) and field seams. Samples of factory seams can either be provided by the liner fabricator or cut out in the field. One factory seam sample per 1,525 meters (5,000 feet) of factory seam is normally required. In accordance with the approved CQA/CQC plans, samples of field seams can either be made separately and alongside the actual installation or cut out from the installed liner. One field seam sample per 152.5 meters (500 feet) of field seam is normally required.

- Location: Both field and factory seams are tested by this method. Exact sampling locations are determined by the CQA inspector.

- Documentation: When taking samples from the field, the CQA inspector must keep accurate records. Samples should be numbered, dated, identified as to the personnel making the seam (if applicable), and keyed to the proper location on a print of the sheet layout. Weather conditions should also be recorded. If the liner fabricator is supplying the factory seam samples, each must be numbered, dated, and keyed to the appropriate liner panels when the samples are taken. The laboratory test report should include the following: sample identification, method of preparing specimens, type of test specimen and dimensions, number of specimens tested, speed of testing, and breaking factors.

- Interpretation: Field and factory seam breaking factor values which are 80 percent or greater of the specified minimum strength of the parent material are acceptable. For HDPE, field and factory seam values 80 percent or greater of the specified minimum yield strength of the parent material are acceptable. Where a combination of dissimilar materials is involved, the value should be 80 percent of the weaker material. Lesser values are not acceptable and could warrant additional sampling and testing and possible rejection of the seams in question.

- Limitations: Performance of this test requires special test equipment and trained personnel. Although accelerated aging of seam samples may be used to obtain quick results, the time required from initial sampling to documentation of test results is a minimum of 2 weeks (with the exception of HDPE which requires no waiting time for cure). During this time, the lining could be buried under a leachate collection system or a protective earth cover before the test results are known.

- Alternatives: None. This is a mandatory test.

Bonded Seam Strength in Shear of Reinforced FMLs (ASTM D 751, Modified Grab Method A - Testing Coated Fabrics)

- Purpose: This is a laboratory test designed to determine the breaking strength (pounds) of seams in shear for reinforced FMLs.

- Method: Specimens 10 centimeters (4 inches) wide and a minimum length of 23 centimeters (9 inches) plus the seam width are prepared from the sample material. Five specimens are tested. Each specimen is placed in the 2.5-centimeter (1-inch) wide grips of a testing machine which consists of a straining mechanism, clamps for holding the specimen, and a load recording mechanism. Seams should have cured for a minimum of 12 days prior to testing. Each specimen is strained at a uniform speed of 30.5 centimeters (12 inches) per minute. The maximum load for each specimen is recorded. The load at break is recorded for each specimen.

- Frequency: Specimens should be taken from samples of both factory and field seams. Samples of factory seams can either be provided by the liner fabricator or cut out in the field. One factory seam sample per 1,525 meters (5,000 feet) of factory seam is normally required. Samples of field seams can either be made up separately and alongside the actual installation or they can be cut out from the installed liner. One field seam sample per 152.5 meters (500 feet) of field seam is normally required.

- Location: Both field and factory seams are tested by this method. Exact sampling locations are determined by the CQA inspector.

- Documentation: The CQA inspector must maintain accurate records of the samples. Samples should be numbered, dated, identified as to the personnel making the seam (if applicable), and keyed to the proper location on a print of the sheet layout. Weather conditions should also be recorded. The laboratory test report should include the following: sample identification, method of preparing specimens, specimen dimensions, number of specimens tested, speed of testing, and breaking strengths.

- Interpretation: Field seam and factory seam breaking strengths which are 80 percent or greater of the specified strength of the parent material are acceptable. Lesser values are not acceptable, and could warrant additional sampling and testing and possible rejection of the seam in question.

- Limitations: Performance of this test requires special test equipment and trained personnel. Although accelerated aging of seam samples may be used to obtain quick results, the time required from initial sampling to documentation of test results is a minimum of 2 weeks. During this time, the FML could be buried under a leachate collection system or a protective earth cover before the test results are known.

- Alternatives: None. This is a mandatory test.

Bonded Seam Strength in Peel (ASTM D 413, Modified Machine Method, Type A - Test Methods for Rubber Property - Adhesion to Flexible Substrate)

- Purpose: This is a laboratory test designed to investigate the strength of factory and field seams when tested in peel.

- Method: Specimens 2.5 centimeters (1 inch) wide and a minimum length to permit 90-degree peel separation are cut from the sample material. Five specimens are tested. Seams should have cured for a minimum of 12 days prior to testing, except for HDPE which does not need to cure. Each specimen is placed in the grips of the same testing machine as that used in the grab method for breaking strength. Each specimen is separated by hand to permit the jaws of the testing machine to be attached to the individual sheets. The specimen is stripped at a jaw separation rate of 5 centimeters (2 inches) per minute and at an angle of approximately 90 degrees. The separation is continued for a sufficient distance to ensure seam adhesion.

- Frequency: Specimens should be taken from samples of both factory and field seams. Samples of factory seams can either be provided by the liner fabricator or cut out in the field. One factory seam sample per 1,525 meters (5,000 feet) of seams can either be made up separately and alongside the actual installation or they can be cut out from the installed liner. One field seam sample per 152.5 meters (500 feet) of field seam is normally required.

- Location: Both field and factory seams are tested by this method. Exact sampling locations are determined by the CQA inspector.

- Documentation: The CQA inspector must maintain accurate records of the samples. Samples should be numbered, dated, identified as to the personnel making the seam (if applicable), and keyed to the proper location on a print of the sheet layout. Weather conditions should also be recorded. The laboratory test report should include the following: sample identification, method of preparing specimens, specimen dimensions, number of specimens tested, speed of testing, adhesion value (if applicable), and type of failure (at the seam interface, by delamination of the sheet, or by tearing of the sheet).

- Interpretation: Peel test results will identify any problems with the seaming techniques or materials. Well bonded reinforced materials should fail due to delamination of one of the sheets. This indicates that the bond strength between the two sheets is stronger than the ply adhesion of the sheets. Well bonded HDPE and unreinforced PVC seams, when tested in peel, should fail due to tearing of one of the sheets. This indicates that the bond strength between the two sheets is as strong as the parent material.

- Limitations: Special test equipment and trained personnel are required to perform this test. Although accelerated aging of seam samples may be used to obtain quick results, the time required from initial sampling to documentation of test results is a minimum of 2 weeks (HDPE is an exception, since there is no waiting time for cure). During this time, the FML could be buried under a leachate collection system or a protective earth cover before test results are known.

- Alternatives: None. This is a mandatory test.

CHAPTER 9

FML COVERS

INTRODUCTION

FML covers will generally consist of one of the following materials:

- Earth:

    - Clay (natural and/or bentonite added).
    - Sand.
    - Silt.
    - Gravel.
    - Combination of soils.

- Other:

    - Portland cement/gunite.
    - Geotextile.
    - Drainage net.

Most of these covers are placed over an FML as a protective layer against mechanical, weather, or other potential damage. Drainage nets and sand and gravel are used as a permeable layer to convey leakage and/or leachate that may accumulate on the upper and/or lower FML after being put into use.

EARTH COVERS

The earth cover to be used may originate on site or may be imported from off site. An access ramp and dumping pad are typically prepared over one or several areas of the FML installation; the cover is deposited in these areas by a scraper, dump truck, or wheel/track loader (see Figures 9-1 and 9-2). The earth is then spread over the FML to the specified depth using a track dozer (for which low ground pressure is desirable) and/or motor grader (see Figure 9-3). Grade stakes with brightly colored flags that sit on top of the liner are used to ensure proper cover depth. Equipment and grade stakes are shown in Figures 9-3 and 9-4.

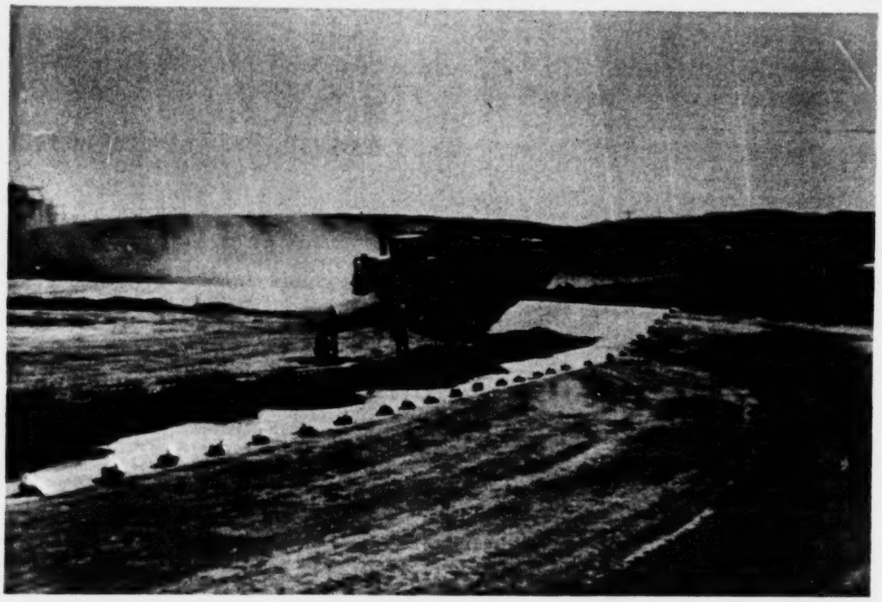


Figure 9-1. Scraper depositing cover soil onto FML.

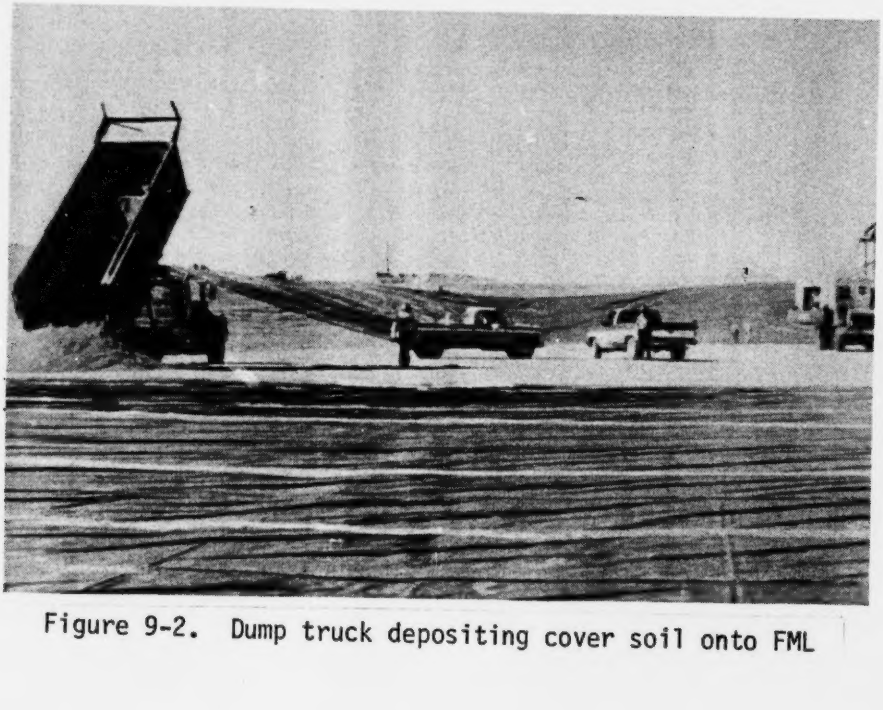
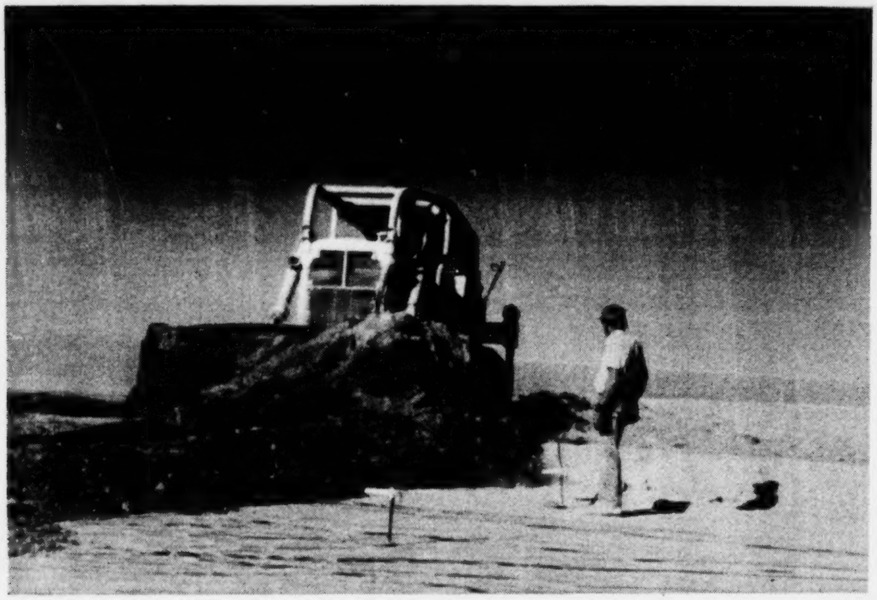


Figure 9-2. Dump truck depositing cover soil onto FML



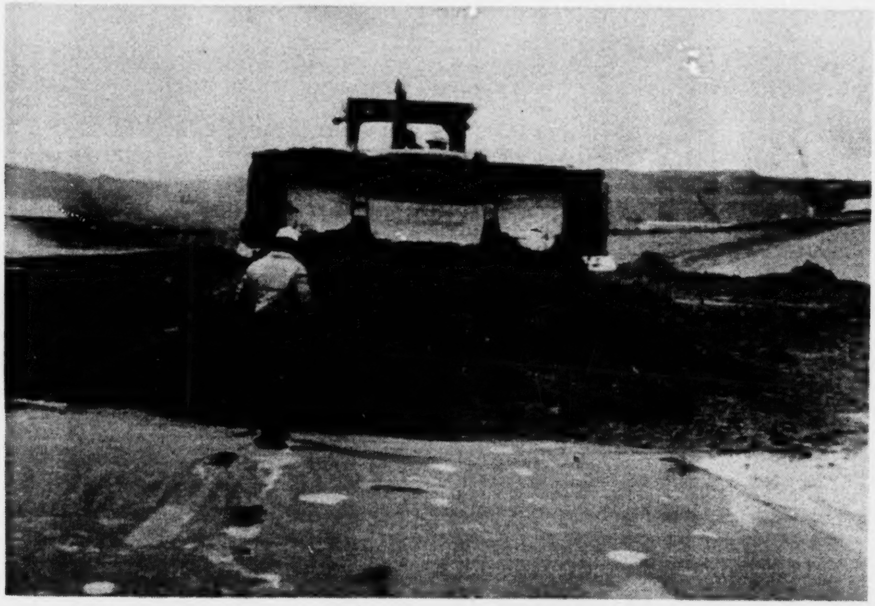


Figure 9-3. Spreading cover soil with track dozer

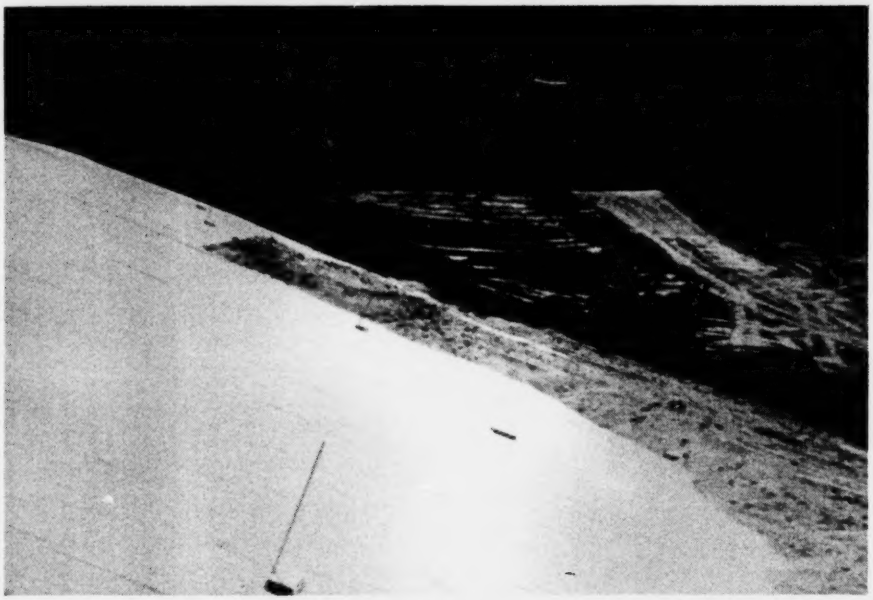


Figure 9-4. Grade stakes on top of FML.

Equipment

One or more of the following pieces of equipment are generally used to place earth cover over FML:

- Scraper, loader, and/or dump truck to deposit earth on the FML.
- Grade stakes with brightly colored flags to ensure proper cover depth.
- Track dozer and/or motor grader to spread the earth over the FML.

All equipment should be present at the site and in proper working order prior to commencement of covering operations. Grade stakes should be prepared ahead of time to avoid unnecessary delays.

Inspection Procedures--

- Method: Observe all cover placement equipment to ensure that appropriate types and numbers are on site. Observe the check-out of each piece of equipment, as appropriate, to ensure that they are in proper working order.
- Frequency:
  - Once prior to commencement of cover placement on the FML.
  - Daily after placement operations commence.
- Documentation: The CQA inspector should maintain an accurate log in the daily diary noting the presence and workability of all equipment.
- Interpretation: All required equipment must be on site and in working condition prior to commencement of cover placement on the FML. Once cover placement begins, all equipment is to be kept in working order or replaced.

Personnel

Personnel responsible for cover placement should be properly qualified and should wear appropriate shoes when walking on the FML.

Qualifications--

Personnel responsible for covering the FML should be highly experienced in order to prevent possible damage to the FML by equipment during cover operations. The contractor should provide the inspector with certification that the equipment operators are qualified to perform cover operations. In addition, all personnel should receive instruction on the purpose of FML installation and on cover placement procedures.

Inspection Procedures--

- Purpose: All equipment operators should have proper qualifications and training.
- Method: All personnel should complete a signed statement confirming that they are qualified equipment operators and that they have received at least the minimum training with regard to the purpose of FML installation and cover placement procedures.
- Frequency: An inquiry of qualifications should be made prior to personnel beginning work on cover placement.
- Documentation: The record of each installer, by name, should be maintained in the daily diary.
- Interpretation: No equipment personnel should work on the FML project without proper qualifications or training.
- Alternatives: The FML installation contractor could provide the required information to the inspector rather than the inspector requesting signed statements.

Clothing

All personnel who are likely to walk on the uncovered FML must wear smooth-soled shoes. No shoes with indented patterns should be worn, since rocks can be trapped in the void areas and inadvertently puncture or tear the FML.

Personnel should wear leather gloves to prevent possible burns from contact with sun-exposed FML and possible blisters from long-term use of hand-operated equipment.

Inspection Procedures--

Method: Each installer should be inspected to ensure that his clothing and footwear is of the type (e.g., smooth-soled shoes and leather gloves) that will not damage the FML or injure the installer during cover placement.

Frequency: Each crew must be observed prior to the start of work each day.

Locations: All crews should be observed.

Documentation: A record of each installer, by name, should be maintained in the daily diary, and unacceptable apparel noted.

Interpretation: All persons handling or working on the FML should conform to acceptable dress requirements.

Alternatives: The liner contractor could assume responsibility for a daily check of his employees. The CQA inspector would then receive an acceptance report from the contractor and make spot observations throughout the day for noncompliance.

Weather Conditions

The inspector should be aware that earth cover is not to be placed in certain weather conditions. These include:

- Rainy days.
- Extremely windy days.
- Extremely cold days when the earth is or could become frozen. Frozen earth clods could cause puncturing of the FML when placed.

Inspection Procedures--

- Method: Observe weather conditions at the site for severe winds, rain, and severe cold.
- Frequency: Weather conditions should be observed throughout the day.
- Documentation: Wind velocities, temperatures, and moisture conditions at the site should be periodically recorded throughout the day in the daily diary.
- Interpretation: Work on the FML cannot proceed during periods of severe wind, rain, or severe cold.

Earth Cover Placement

Placement of earth cover includes setting grade stakes, transporting the cover onto the FML surface, and spreading the cover to the specified depth. Earth cover should be placed and spread as soon as possible after the FML is in place and has been seamed, anchored, and tested.

Setting of Grade Stakes--

Grade stakes are placed on the FML surface at many locations to assist the equipment operator/inspector in obtaining the specified cover thickness. Grade stakes for use in cover installation are constructed with a flat base that can be set on the FML surface without damaging it (see Figures 9-3 and 9-4). Plastic traffic cones may also be used, as shown in Figure 9-5. Grade stakes should be moved about as the cover is being placed, so that they do not remain on the FML.

Transport of Earth Cover--

All earth cover must be free of debris, vegetation, sharp rocks, or any other material that could damage the FML. If an access ramp and dumping pad are used to deposit the cover material, they must be periodically relocated so that the ramp/pad does not become overly compacted. Figure 9-1 shows a scraper descending an access ramp with a load of earth cover.

Spreading of Earth Cover--

Earth cover should not be spread over an FML if rain or other conditions have rendered the supporting surface spongy or otherwise unstable. Ideally, the supporting surface should be dried and newly prepared. However, in some cases, a geotextile placed over the unstable area can provide sufficient supporting surface for the FML.

The FML must be protected from undue stress from the equipment during cover placement. The equipment should not:

- Operate directly on the lining.
- Slip or run off the earth cover.
- Operate on earth cover of insufficient depth.
- Operate without spark arrestors (diesel equipment only).
- "Hit the pile" of cover with spreading equipment, causing the FML to stretch or tear.
- Have blades that cut too deeply into the partially compacted stockpiles of earth cover atop the FML, causing it to stretch or tear. It is sometimes appropriate to back-drag the earth cover material to avoid the wrinkling of excess or stretched liner material. Figure 9-6 shows an FML damaged during the spreading of earth cover.

Inspection Procedures--

One inspector should be available to observe each piece of equipment as it transports and spreads the earth cover. Figure 9-3 shows earth cover being properly spread on an FML by a track dozer; note the grade stakes and the presence of the inspector.

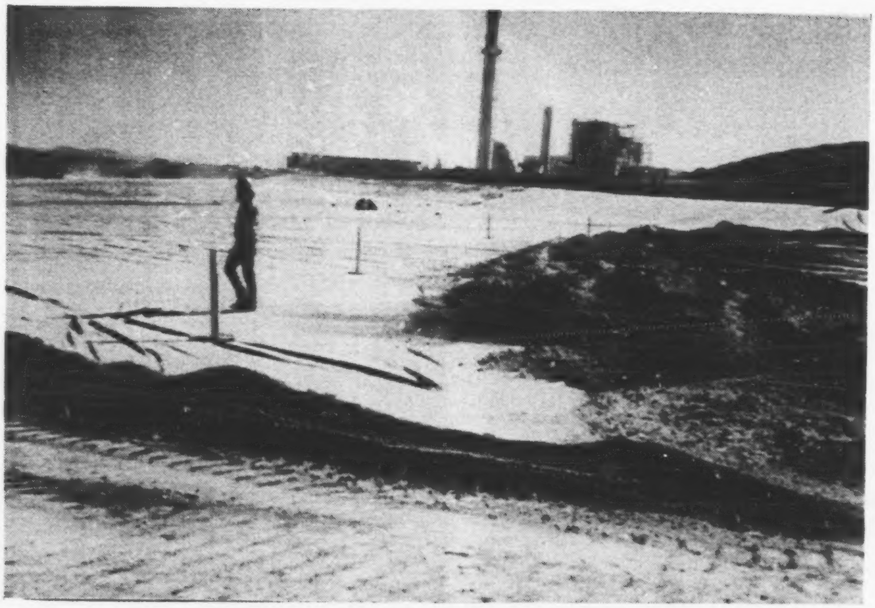


Figure 9-5. Traffic cones on top of FML

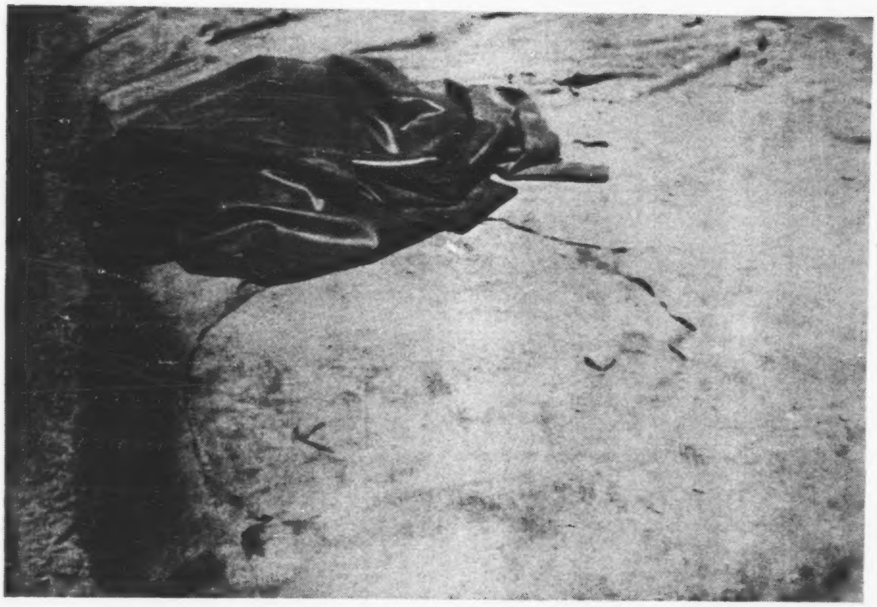


Figure 9-6. FML damage during spreading of earth cover

- Purpose: To ensure that the specified earth cover material is applied at the specified depth without damaging the FML.

- Method: The contractor should provide the inspector with test reports on the characteristics of the cover material to be applied to ensure that they meet specifications.

  Visual observations should be made of the following:

  - Cover material as it is being applied to ensure that no large or sharp rocks or objectionable matter are present.

  - The equipment spreading the cover material to ensure that a minimum of 30.5 centimeters (12 inches) is maintained between the bottom of the equipment and the FML, and that the FML is not damaged.

  - Grade stakes with flat bottom supports or traffic cones used to monitor for specified cover depth.

  - Specified depth of the earth cover is achieved.

- Frequency: Inspection should be ongoing.

- Location: The entire earth cover material placement operation should be inspected.

- Documentation: The following information should be recorded in the CQA inspector's daily diary:

  - Cover material characteristics as supplied by the contractor and as observed.

  - Type of equipment used to transport and spread cover material.

  - Final depth of material placed.

  - Was the FML damaged? If so, how was it repaired and retested?

  - The name of the equipment operator(s) placing the cover material.

- Interpretation: The entire FML should be covered as specified. Any area of suspected FML damage must be uncovered and properly repaired before the FML installation can be accepted. All work should be done only in the presence of the inspector(s) and on a one-to-one basis, i.e., one machine, one inspector.

- Limitations: Visual observation for FML damage during earth cover application is sometimes superficial. Further, even if damage to the FML is suspected, it may be difficult to locate because of the overlying cover material.

- Alternatives: None. Visual observation is mandatory.

PORTLAND CEMENT CONCRETE/GUNITE

In some cases, a Portland cement concrete or gunite cover will be used to protect an FML from damage. This type of cover is either sprayed or poured onto the surface of the FML. To prevent cracking of the cover, reinforcing steel may be used.

Equipment

Standard equipment is used to place Portland cement concrete or gunite cover onto the FML. Figure 9-7 shows gunite being sprayed onto a FML surface.

Inspection Procedures--

Similar to the Inspection Procedures subsection for equipment used for earth cover placement.

Personnel

Similar to the Personnel subsection for earth cover placement.

Weather Conditions

Similar to the Weather Conditions sub section for earth cover placement.

Portland Cement Concrete/Gunite Placement

The following practices should be adhered to when placing Portland cement concrete and gunite on an FML surface:

- Reinforcing steel should be placed on chairs that sit on top of the FML, as shown in Figure 9-8.

- The gunite material should be sprayed onto the FML from an adequate distance to avoid puncturing the FML.

Inspection Procedures--

- Introduction: One inspector should be available to observe each piece of equipment that is involved in placing the Portland cement concrete or gunite. The inspector(s) should also observe all personnel involved.

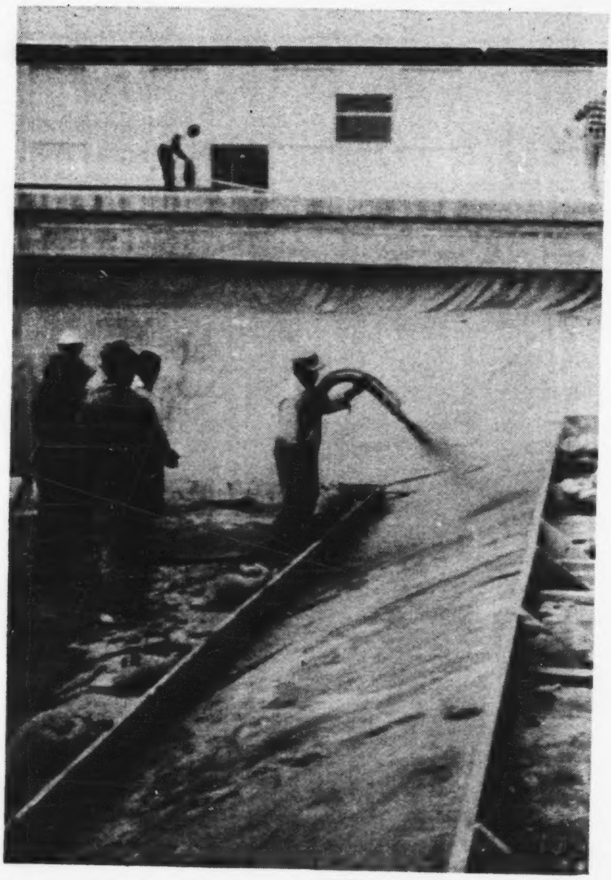


Figure 9-7. Gunite being sprayed onto FML

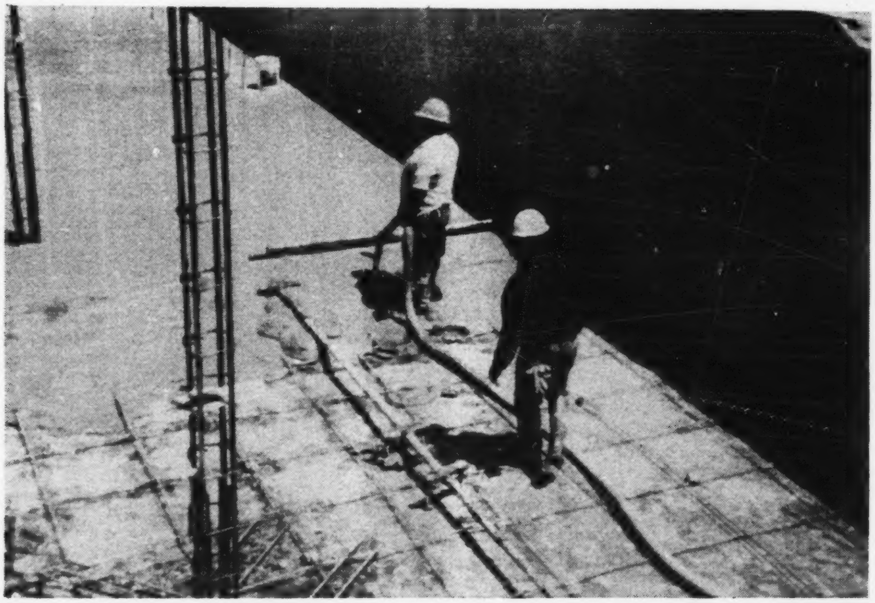


Figure 9-8. Reinforcing steel setting on chairs

- Purpose: To ensure that the specified cover material is applied at the specified thickness and finished without damaging the FML.

- Method: The contractor should provide the inspector with test reports on the characteristics of the cover materials to be applied to ensure that they meet specifications. The inspector should take samples of applied materials for testing strength after cure in accordance with the specifications.

  Visual observations should be made of the following:

  - FML is clean and free of debris to receive cover material.
  - No lumps, unmixed materials, or objectionable matter are present.
  - The equipment used to apply the cover materials does not come into contact with and damage the FML.
  - Reinforcing steel, if any, is properly placed and supported.
  - Screeds or other means to measure depth are used to ensure that the material is applied to the specified depth.
  - Cover material is finished with a surface that is in compliance with the specifications.

- Frequency: Ongoing throughout applications.

- Location: The entire cover material placement operation should be inspected.

- Documentation: The following information should be recorded in the CQA inspector's daily diary:

  - Cover material characteristics as supplied by the contractor and as observed.
  - Location, date, time, and type of samples taken for strength testing.
  - Type of equipment used to transport and apply cover material.
  - Was the FML damaged? If so, how was it repaired and retested?

  - The names of all personnel involved in applying the material and their work assignments.

- Interpretation: The entire FML should be covered as specified. Any area of suspected FML damage must be uncovered and properly repaired before the FML installation can be accepted. All work should be done only in the presence of the inspector(s) and on a one-to-one basis, i.e., one machine, one inspector.

- Limitations: Visual observation for FML damage during cover material application is sometimes superficial. Further, even if damage to the FML is suspected, it may be difficult to locate because of the overlying cover material.

- Alternatives: None. Visual observation is mandatory.

DRAINAGE NETS AND GEOTEXTILES

Like FMLs, drainage nets and geotextiles are geosynthetics. Drainage nets are used primarily for transmissivity of liquids (leakage) within them, and geotextiles are chiefly used as filters to permit the passage of liquids through them.

Drainage Nets

Drainage nets are generally made of high-density polyethylene. Because of their net construction, they have the ability to transmit significant quantities of liquid with little head loss, and are well suited for drainage layers, particularly on slopes where the placement of a sand or gravel material is not practical due to sloughing. They are also used where a suitable, cost-effective earth material for drainage is not available.

Drainage nets are packaged in rolls. When placed over the FML, a drainage net is rolled out in a manner similar to the placement of rolled FML. Edges are butted together and periodically tied together to provide a continuous layer.

Geotextile

Geotextile is a synthetic fiber in cloth form (woven or nonwoven) used as a filter fabric and as a protective layer over and under an FML. Geotextiles are not subject to biological degradation, and resist chemical attack. Most geotextiles are packaged in rolls. When placed over/under the FML, geotextiles are rolled out in a manner similar to the placement of rolled FML (see Figure 9-9). Edges are overlapped several inches, and are sometimes sewn but generally not attached.

Inspection Procedures

- Purpose: To ensure that the specified drainage net and/or geotextile materials are placed over the entire FML without damaging the FML, and that the method of layout of the drainage net does not leave an exposed edge which can puncture the FML.

- Methods: The CQA inspector should:

  - Obtain a confirmation from the contractor or visually observe that the materials being used are the specified materials and the proper thickness.

  - Observe placement of the geotextile to ensure that the FML is not damaged.

- Frequency: Installation observation should be ongoing.

- Location: The specified area should be covered.

- Documentation: The progress of drainage net and/or geotextile placement should be recorded along with any required repairs.

- Interpretation: All FML damage should be repaired and tested using the appropriate method(s).

- Limitations: Constant observation is required, since it is difficult to locate any damage to the FML covered by the aforementioned materials.

- Alternatives: Earth cover can be used.

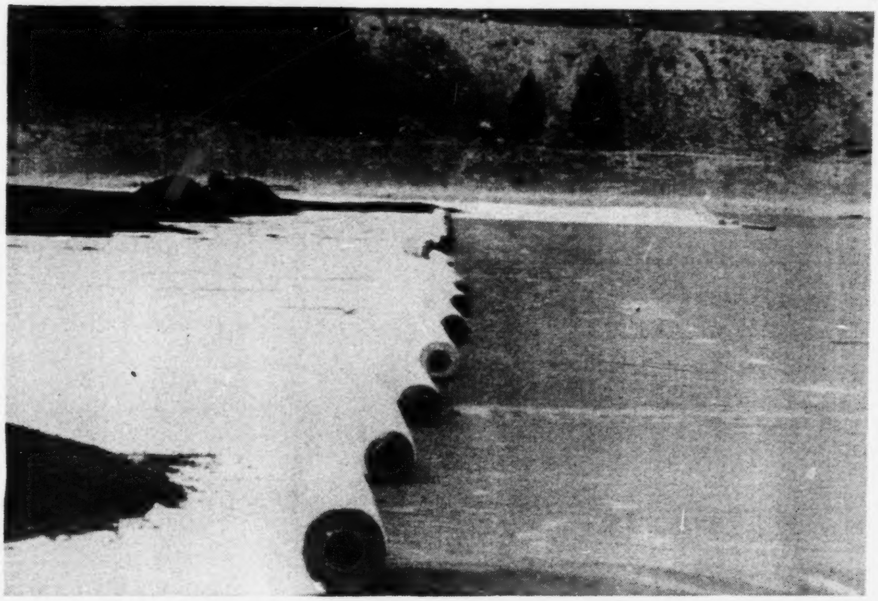


Figure 9-9. Geotextile rolls on FML

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APPENDIX A

INSPECTION CHECKLISTS

INSPECTION CHECKLIST

ON-SITE UNLOADING AND STORAGE

1. MATERIAL CHECK

A. Proper Materials

- FML Type Yes ___ No ___ Status ______________
- FML Thickness Yes ___ No ___ Status ______________
- Solvents, Adhesives, Tapes, etc. Yes ___ No ___ Status ______________

B. Damaged Materials

- FML Yes ___ No ___ Status ______________
- Accessories Yes ___ No ___ Status ______________

2. UNLOADING AND HANDLING EQUIPMENT

A. Proper Equipment Yes ___ No ___ Status ______________

B. In Working Order Yes ___ No ___ Status ______________

C. Trained Operators Yes ___ No ___ Status ______________

3. UNLOADING AREA

A. Accessible to Delivery Trucks Yes ___ No ___ Status ______________

B. Accessible to Handling/ Transfer Equipment Yes ___ No ___ Status ______________

C. Proper Unloading Surface Yes ___ No ___ Status ______________

D. Materials Damaged Yes ___ No ___ Status ______________

E. Proper Placement on Unloading Surface Yes ___ No ___ Status ______________

4. STORAGE AREA

A. Accessible to Transfer/Handling Equipment Yes ___ No ___ Status ______________

B. Proper Unloading Surface Yes ___ No ___ Status ______________

C. Materials Damaged During Loading/Unloading Yes ___ No ___ Status ______________

D. Proper Storage

- PVC, CPE, CSPE, and FML Under Cover Yes ___ No ___ Status ______________
- Ancillary Materials Stored Indoors Yes ___ No ___ Status ______________
- FML Arranged for First In/First Out Use Yes ___ No ___ Status ______________

INSPECTION CHECKLIST

PREPARATION AND MAINTENANCE OF SUPPORTING SURFACE

1. EARTH SUPPORTING SURFACES

A. Vegetation Removal

- All Vegetation/Large Roots Removed Yes ___ No ___ Status ____________
- Herbicide Properly Applied Yes ___ No ___ Status ____________

B. Burrowing Animals/Pests

- Burrowing Animals/Pests Have Been Eliminated Yes ___ No ___ Status ____________
- All Burrows/Passages Filled Yes ___ No ___ Status ____________

C. Finished Supporting Surface

- Surface Free of Rocks/Depressions Yes ___ No ___ Status ____________
- Surface Free of Wet Areas and Has Uniform Moisture Content Yes ___ No ___ Status ____________
- Surface Free of Petroleum Products or Other Spills Yes ___ No ___ Status ____________
- Surface Smooth and Ready for Liner Placement (no roots, grade stakes, or abrupt changes in grade; has been rolled and compacted) Yes ___ No ___ Status ____________

D. Maintenance of Supporting Surface

- All Weather/Traffic Damage Has Been Repaired Before Liner Placement Yes ___ No ___ Status ____________

2. OTHER SUPPORTING SURFACES

A. Concrete Supporting Surfaces

- Surface Free of Voids/Projections Yes ____ No ____ Status ________________
- Surface Has Steel Trowel Finish Yes ____ No ____ Status ________________
- Earth Surface Adjacent to Concrete Compacted Yes ____ No ____ Status ________________
- All Expansion Joints Cut Flush Yes ____ No ____ Status ________________
- Abutting Surfaces Have Smooth Transition Yes ____ No ____ Status ________________
- All Corners Coming into Contact with FML Have Rounded Edges Yes ____ No ____ Status ________________
- Concrete Free of Hidden Voids Yes ____ No ____ Status ________________

B. Asphaltic Supporting Surfaces

- Surface Voids Filled Yes ____ No ____ Status ________________
- All Debris Removed from Surface Yes ____ No ____ Status ________________
- All Rough Surfaces Smoothed/Eliminated Yes ____ No ____ Status ________________

INSPECTION CHECKLIST

PLACEMENT OF FML ON SUPPORTING SURFACE

1. PLACEMENT EQUIPMENT

   A. Proper Equipment On Site (see attached list) Yes ___ No ___ Status ______________

   B. Appropriate Quantities Yes ___ No ___ Status ______________

   C. In Working Order Yes ___ No ___ Status ______________

2. PERSONNEL

   A. Properly Trained Yes ___ No ___ Status ______________

   B. Clothing

   - All Workers Must Wear Smooth-Soled Shoes Yes ___ No ___ Status ______________

   - All Workers Must Have Gloves Yes ___ No ___ Status ______________

3. WEATHER CONDITIONS

   A. Weather Is Relatively Calm and Mild (no high wind, rain, snow, severe heat or cold) Yes ___ No ___ Status ______________

4. FML LAYOUT

   A. Layout Plan Prepared Yes ___ No ___ Status ______________

   B. Placement

   - Only Those Sheets That Can Reasonably Be Seamed During the Work Day Are Placed Yes ___ No ___ Status ______________

   - Sheets Unfolded/Unrolled in Same Direction as Wind Yes ___ No ___ Status ______________

- Sandbags Placed on Sheets Yes ___ No ___ Status ______________
- Sheets Placed with Specified Overlap Yes ___ No ___ Status ______________
- Each Sheet/Factory Seam Visually Inspected for Defects Yes ___ No ___ Status ______________

EQUIPMENT FOR FML PLACEMENT

Item	Use
Forklift, front-end loader, and/or flatbed truck	To handle FML sheets for placement
Ladders, wood, flat type	To work on slopes
Wood or plastic dowels with rounded ends, and/or mechanical grips	To assist workers in pulling on edges of FML panels while placing
Chalk line	To assist placing of FML panels
Tape measure (100 feet long)	To measure FML sections
Scissors (bright-colored with rounded points), knife	To cut FML materials
Grade stakes or traffic cones	To measure soil cover depths
Sandbags	To secure unseamed FML panels to prevent damage by wind
Red and yellow keel	To mark FML
Arch punch	To cut holes in FML to fit over anchor bolts
Utility knife, metal sheers	To cut cardboard shipping cartons containing FML and metal bands
First aid supplies	To provide relief from minor injuries
Portable pumps	To pump any accumulated water from supporting surface
Common tool kit (e.g., hammer, saw, etc.)	To make miscellaneous repairs, etc.
Water supply	To supply personnel drinking and equipment cooling needs
Pencil and paper	To write daily reports, etc.
Phone and/or radio communications	To provide off-site contact

INSPECTION CHECKLIST

SEAMING OPERATIONS

1. INSPECTOR ORIENTATION

   A. Inspector Provided with Precise Specifications on Seaming Equipment and Procedures — Yes ____ No ____ Status ________________

   B. Inspector Received Explanation and Demonstration of Seaming Equipment/Procedures to Be Used — Yes ____ No ____ Status ________________

2. SEAMING EQUIPMENT

   A. Proper Equipment On Site (see attached list) — Yes ____ No ____ Status ________________

   B. Appropriate Quantities — Yes ____ No ____ Status ________________

   C. In Working Order — Yes ____ No ____ Status ________________

3. PERSONNEL

   A. Proper Crew Size — Yes ____ No ____ Status ________________

   B. Properly Experienced — Yes ____ No ____ Status ________________

   C. Clothing

      - All Workers Must Wear Smooth-Soled Shoes — Yes ____ No ____ Status ________________

      - All Workers Must Have Gloves — Yes ____ No ____ Status ________________

4. ENVIRONMENTAL CONDITIONS

   A. Weather Relatively Calm and Mild (no high wind, rain, snow, hail, heavy mist, dust, severe heat or cold) — Yes ____ No ____ Status ________________

5. SEAMING

A. Sheets/Patches Properly Positioned with Sufficient Overlap (2"/PVC; 3"/CSPE; 3"/CPE; 1"/HDPE) Yes ___ No ___ Status ______________

B. Sandbags in Place Yes ___ No ___ Status ______________

C. Working Area Clean and Has Adequate Maneuvering Room Yes ___ No ___ Status ______________

D. No Edge Defects Yes ___ No ___ Status ______________

E. Proper Seaming Techniques Followed Yes ___ No ___ Status ______________

EQUIPMENT REQUIRED DURING FML SEAMING OPERATIONS

Item	Use
Scissors (bright-colored with rounded points)	To cut FML materials
Sandbags	To secure unseamed FML panels to prevent damage by wind
Electric generator and extension cords	To operate heat guns, power tools, and lights.
Scrub brushes	To clean FML prior to seaming, patching, anchoring
Fuel	To operate gasoline and/or diesel equipment
Extra pieces of FML	To use as a tarp to store materials on the seaming area, and for patches
Ladders	For working on slope
Seaming equipment:	
- Tape	For measuring
- Clean bristle brushes 7.5 cm (3 inches) wide x 10 cm (4 inches) long, squeeze bottles, caulk guns	To apply adhesive, cement, solvent caulk, etc.
- Hand rollers	To apply pressure to seam after application of adhesive, cement, and solvent
- Clean, absorbent white cotton rags	To clean FML in area of seam and to wipe excessive adhesive
- 10-cm (4-inch) dia plastic funnel	To assist in pouring adhesives and solvents from one container to another
- 3.785-liter (1-gallon) polyethylene pails	To hold adhesives and solvents
- Wood boards	To provide support under FML during seaming operations
- Heat guns	To warm FML during seaming operations

FML SEAMING EQUIPMENT (continued)

Item	Use
- Heat sealing equipment	Commonly used on HDPE, sometimes used on other FML types
- Grinding equipment	For preparation of HDPE seams
- Fusion welding equipment	For HDPE seaming
First aid supplies	To provide relief from minor injuries
Mechanics tool kit	To make miscellaneous repairs
Water supply	To supply personnel drinking and equipment cooling needs
Phone and/or radio communications	To provide off-site contact
Fire extinguishers	Use for fires

INSPECTION CHECKLIST

LINER ANCHORS AND ATTACHMENTS

1. PLACEMENT EQUIPMENT

   A. Proper Equipment Yes ____ No ____ Status ________________

   B. Appropriate Quantities Yes ____ No ____ Status ________________

   C. In Working Order Yes ____ No ____ Status ________________

2. PERSONNEL

   A. Properly Experienced Yes ____ No ____ Status ________________

   B. Clothing

   - All Workers Must Wear Smooth-Soled Shoes Yes ____ No ____ Status ________________
   - All Workers Must Have Gloves Yes ____ No ____ Status ________________

3. ANCHORS AND ATTACHMENTS

   A. Anchor Trenches

   - Trench Depth/Width Adequate Yes ____ No ____ Status ________________
   - Sufficient Distance from Trench to Top of Slope Yes ____ No ____ Status ________________
   - Leading Edge of Trench Smooth/Free of Sharp or Jagged Edges Yes ____ No ____ Status ________________
   - FML Properly Installed in Trench Yes ____ No ____ Status ________________
   - Trench Fill Free of Sharp Rocks Yes ____ No ____ Status ________________
   - Final Backfilling and Compaction Operations Damaged FML Yes ____ No ____ Status ________________

B. Concrete and Piping	Yes ___	No ___	Status ___________
- Surface Smooth, Free of Voids, Jagged Edges, Burrs, Sharp Protrusions	Yes ___	No ___	Status ___________
- Batten Strip and Nuts/ Bolts Compatible	Yes ___	No ___	Status ___________
- Batten Materials Consistent with Design	Yes ___	No ___	Status ___________
- Adhesives, Tapes, Caulks Cements Consistent with FML Manufacturer's Recommendations	Yes ___	No ___	Status ___________
- Materials Fresh, Free of Defects, and of Proper Dimensions	Yes ___	No ___	Status ___________
- Reglets Properly Set in Concrete/Flush with Concrete Surface	Yes ___	No ___	Status ___________
- No Voids Exist in Concrete Alongside Reglet	Yes ___	No ___	Status ___________
- Reglet of Material and Size Specified	Yes ___	No ___	Status ___________
- FML Edge Properly Inserted into Reglet	Yes ___	No ___	Status ___________
- Rubber Rod Properly Inserted	Yes ___	No ___	Status ___________
- Caulk Bead of Proper Material and Properly Placed	Yes ___	No ___	Status ___________
- Attachment to Pipe Is According to Plans and Specifications	Yes ___	No ___	Status ___________
- All Potential Leak Paths Around Pipe Have Been Properly Caulked	Yes ___	No ___	Status ___________

INSPECTION CHECKLIST

TESTING

1. FIELD TESTS

Test Method: ______________________________

A. Proper Equipment (consistent with FML and seam) Yes ___ No ___ Status ____________

B. In Working Order Yes ___ No ___ Status ____________

C. Personnel

- Properly Experienced Yes ___ No ___ Status ____________
- Proper Clothing (smooth-soled shoes) Yes ___ No ___ Status ____________

D. Defective Sheets/Seams Repaired/Retested Yes ___ No ___ Status ____________

2. LABORATORY TESTS

A. Specified Number of Samples Taken Yes ___ No ___ Status ____________

B. Proper Equipment Yes ___ No ___ Status ____________

C. Trained Personnel Yes ___ No ___ Status ____________

D. Tests Performed

- ASTM D 3083 Yes ___ No ___ Status ____________
- ASTM D 751 Yes ___ No ___ Status ____________
- ASTM D 413 Yes ___ No ___ Status ____________

E. Defective Seams Repaired/Retested Yes ___ No ___ Status ____________

INSPECTION CHECKLIST

FML COVERS

1. EARTH COVERS

A. Proper Equipment Yes ___ No ___ Status _______________

B. In Working Order Yes ___ No ___ Status _______________

C. Personnel

- Properly Experienced Yes ___ No ___ Status _______________
- Smooth-Soled Shoes Yes ___ No ___ Status _______________

D. Weather Mild; Not Rainy, Extremely Cold, or Windy Yes ___ No ___ Status _______________

E. Earth Cover Material Unfrozen, Free of Debris, Vegetation, Sharp Objects Yes ___ No ___ Status _______________

F. Access Ramp and Dumping Pad Periodically Relocated to Prevent Overcompaction Yes ___ No ___ Status _______________

G. Grade Stakes Set/Specified Depth Achieved Yes ___ No ___ Status _______________

H. Was FML Damaged? Repaired/Retested? Yes ___ No ___ Status _______________

2. PORTLAND CEMENT CONCRETE/GUNITE

A. Proper Equipment Yes ___ No ___ Status _______________

B. In Working Order Yes ___ No ___ Status _______________

C. Personnel

- Properly Experienced Yes ___ No ___ Status _______________
- Smooth-Soled Shoes Yes ___ No ___ Status _______________

D. Weather Mild, Not Rainy, Extremely Cold, or Windy Yes ___ No ___ Status _______________

E. Placement

- FML Clean, Free of Debris Yes ___ No ___ Status ____________
- Reinforcing Steel Properly Placed and Supported Yes ___ No ___ Status ____________
- Material Applied to Specified Depth Without Damage to FML Yes ___ No ___ Status ____________

3. DRAINAGE NETS AND GEOTEXTILES

A. Proper Material/Thickness Yes ___ No ___ Status ____________

B. Was FML Damaged? Repaired/Retested? Yes ___ No ___ Status ____________